CHAPTER V

RESEARCH

A. GENERAL

Research as related to tropical cyclones has been limited in the past four years of JTWC's existence; however, during the first half of 1963, significant applied research versus basic research should be accomplished.

The increase of two forecasters in July and August for the 1962 season provided three achievements, meteorologically and operationally, namely:

1. Issuance of JTWC standard operating procedures.
2. Typhoon tracks were our best product through judicious application of operational concepts contained in Chapter I. One by-product of best tracking was the partial isolation of speed of movement as a problem area for future study.
3. Completed preparation of the "Annual Typhoon Report" in January vice April of previous years.

B. ANNUAL REPORT

This "Annual Typhoon Report" was prepared as the 1962 season progressed. The individual typhoon reports of Chapter IV have been put in outline form to highlight the pertinent data particularly for the operators or non-meteorologists. Chapter III has been enlarged to accommodate the meteorologist by consolidating the sequence of events from formation through dissipation stage and correlating them with all 24 typhoons of this season.

A bibliography has been added as Appendix B for cross-reference to all articles and evaluations contained herein, in order to properly credit the forecast techniques or ideas and broaden the base of the report.

An effective major easterly wave analysis and sequential numbering program was started on 1 March by FWC for the 1962 season. Forty percent of these spawned tropical cyclones that required warnings. Since this operational concept is normal for tropical meteorologists, further expansion will not be made except to advise of the many internal references and charts containing easterly wave data within this report. The 1963 FWC easterly wave program includes identification of minor easterly waves on a monthly basis.

"Best Track" evaluation for the charts in Chapter IV is restated for the record. The best track of a tropical cyclone is determined from postanalysis by using the data from the surface, gradient level, 850mb level, pilot reports, land radar reports, and scheduled reconnaissance radar and penetration reports. Tropical cyclones seldom move in a straight line; however, JTWC forecasts a mean track for its warnings. Tropical cyclones usually oscillate to the right and left of a straight line path particularly S of the ridge line while still in the easterlies (18). The amplitude of their oscillatory track varies with forward speed and intensity. The cyclone has a fluid forward movement with expected abrupt changes in the speed and direction of movement. Curvatures and/or loops are a reflection of these abrupt changes. Any "fix" and/or eye passage data that reports the position of the cyclone to be off track is disregarded after thorough investigation (5) (15).

C. RESEARCH

Research will be divided into three types for the 1963 season:

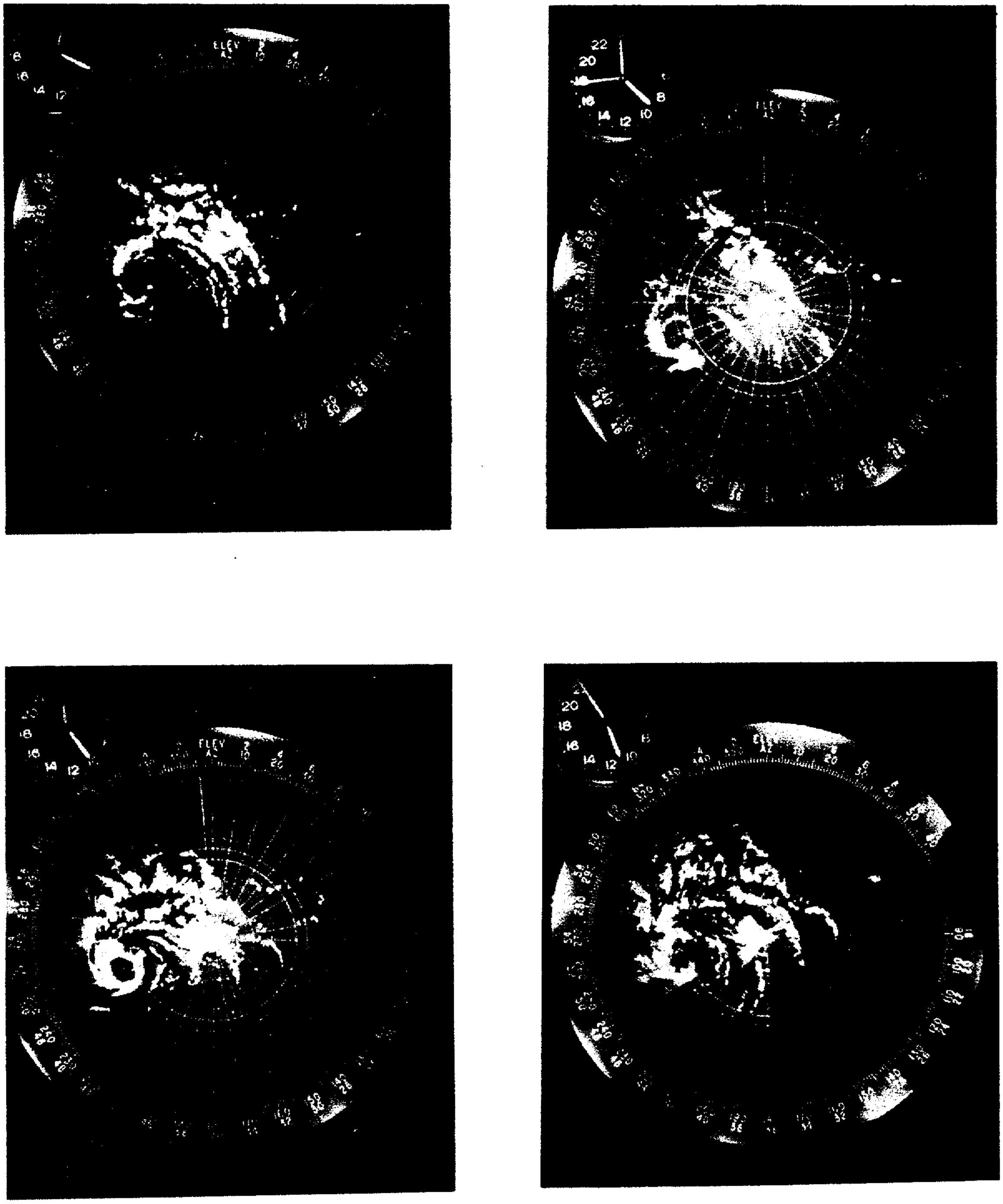
1. Simplification of forecast procedures
2. Improvement of the forecast techniques
3. Examination of the tropical cyclone, which will include a documentation of the cyclone from the formation to typhoon stage, and to obtain more information about the structure of the typhoon eye.

Many peculiarities of eye structure are known to exist: such as, pressure and geographical centers which can be but are not always the same, non-circular eyes, clear and cloudy eyes, non-vertical axis of centers, pulsations of the wall cloud, etc. The latter of these primarily indicates the strength of the typhoon itself as in the case of Typhoon GEORGIA. She provided a 24-hour cycle over a period of 4 days as she passed to the W of Guam. At 0000Z each day, her wall clouds were full and completely circular; whereas, at 1200Z one of the quadrants was open, normally the E quadrant. The surges of GEORGIA to a full eye had a direct correlation with the time of minimum height differential between the surface and the 850mb level. By comparison, Typhoon SARAH's surge cycle was four hours. The pulsation case of Typhoon SARAH is shown in the following Kadena Air Base CPS-9 photographs. These peculiarities should be the topic of a series of papers in future reports.

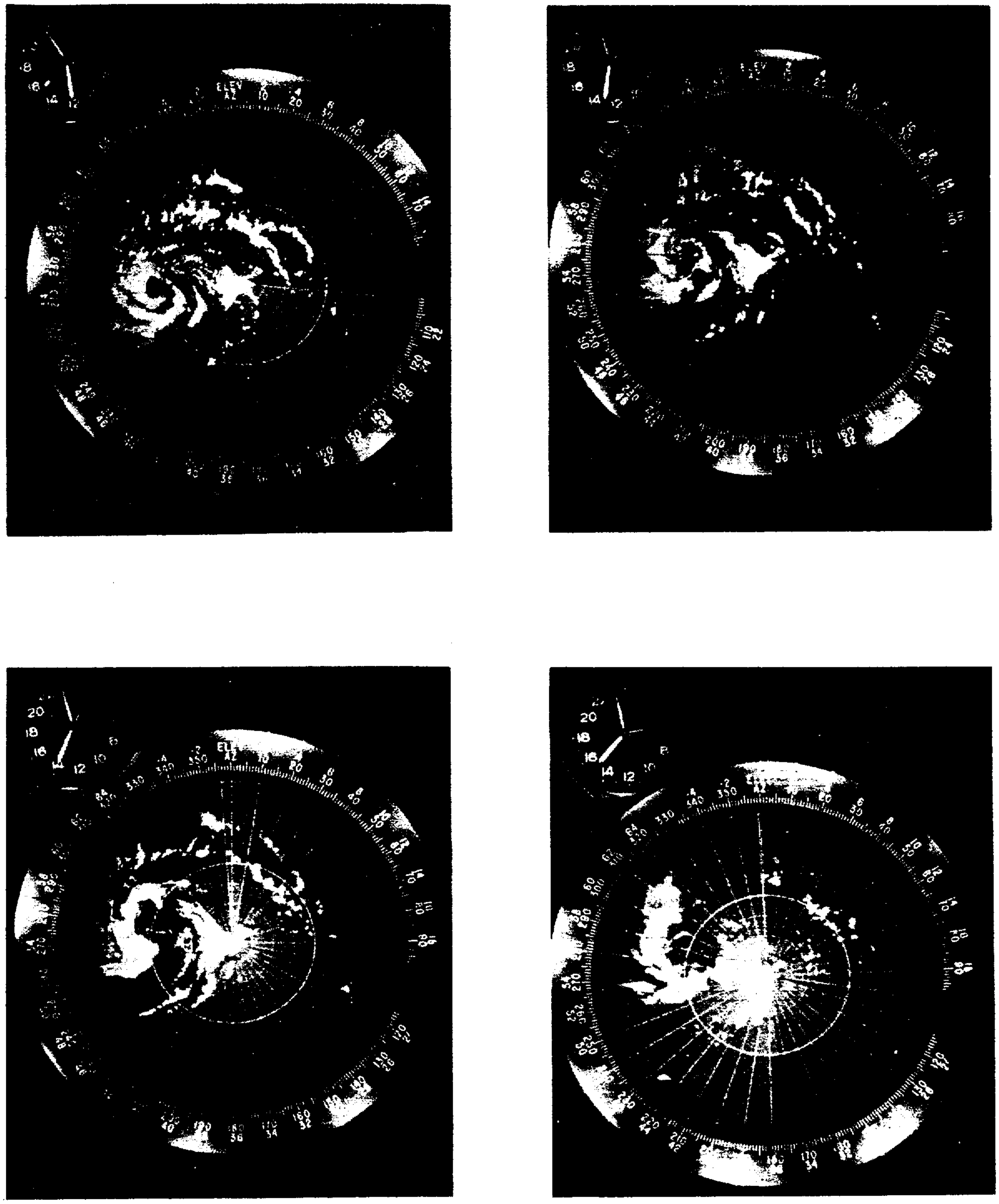
D. PROJECTS AND PAPERS

Projects and papers contained in this chapter are as follows:

1. Typhoon Forecasting
2. Evaluation of Statistical and Computer Typhoon Forecasting Procedures
3. Typhoon Acceleration after Recurvature
4. Typhoon Eye Terminology
5. Investigation of Typhoon Surface Gusts
6. Typhoon Tracks, 1953-1962



TYPHOON SARAH 19 AUGUST 1962
INDIA TIME ZONE
RANGE: 200 MILES



TYPHOON SARAH 19 AUGUST 1962
INDIA TIME ZONE
RANGE: 200 MILES

TYPHOON FORECASTING

by

Lt Colonel Leonard H. Hutchinson, USAF

I. Introduction

Typhoon forecasting is the most challenging and perplexing in the field of meteorology for those who are or have been associated with the program. Sparse upper air coverage, the average of one surface report for every 250,000 square miles in the Western Pacific, and limited aerial weather reconnaissance establish a weak base for analysis and evaluation of the synoptic sequence of events in the formation of tropical cyclones. In addition, the Joint Typhoon Warning Center is austerely manned to meet the operational forecast requirements, excluding the needed basic and applied research to support improvement of forecasting techniques. Research emphasis should be proportional to the frequency of occurrence for these phenomena which in 1962 numbered 24 typhoons in Western North Pacific to 3 hurricanes in the North Atlantic.

This paper is prepared to record the synoptic relationships observed in tropical cyclone formation and movement. Its condensed style provides a summary of many facets in typhoon development which, if singularly expanded with additional data, time, and research personnel, could contribute measurably to this important program. The 1962 season is documented briefly by the consolidated typhoon write-ups and singular data sheets and charts as contained in Chapters III and IV, respectively.

The combined 1962 Air Force and Navy reconnaissance program of two squadrons with six aircraft each stationed on Guam is basically adequate to support only the operational fixes required for tropical cyclones in warning status. In several previous years, these squadrons possessed twelve aircraft each, which provided continued synoptic and special reconnaissance during warning status in addition to the operational fixes.

II. Scope

The interzonal or latitudinal considerations are prerequisites in tropical cyclone forecasting since the position and movement of troughs and ridges in the westerlies affect both formation and movement of tropical cyclones. These features are evident only by meticulous analysis. Examples are pressure or contour changes, latitude of the subtropical ridge, the rate at which the easterlies and westerlies increase or decrease with height, and Northern Hemisphere upper-air analysis of the long waves with particular reference to the number existing and their state of progression.

The interaction between high and low latitudes and between high and low levels within the tropics then becomes the forecasting key. This concept is derived from the long wave analysis (6) which applies from the formation of tropical cyclones through their maturity to dissipation.

III. Formation

Detection of developing tropical cyclones from surface observations (7) becomes routine as pressure, wind, weather, sea swell, and tide observations approach or pass above or below normal criteria for these parameters.

Operational procedures as described in Chapter I guide the analysis from which the resulting aerial investigations are scheduled and/or warnings are issued. Preset tracks, tailored to fit the synoptic situation and performed by the two reconnaissance squadrons, were invaluable in supplementing the seven Trust Territory stations. Analysis of the equivalent potential temperature (θe) on time or space-cross sections (1) was extremely valuable as a routine forecast tool. When θe exceeded 340°A, formation was possible. Normally, the tropical analysis S of 20N was confined to identifying tropical systems for their type, intensity, and speed of movement. The basic tropical systems are known as the easterly wave, the vortex, and the intertropical zone of convergence (ITC).

Forecasting formation or intensification of tropical depressions, which are tropical systems with less than 34 kts sustained winds, from easterly waves or vortices was initially postulated by Riehl's (14) concept of the superposition of a long wave over a major easterly wave in the tropics. Upon fracture of these systems, subsequent intensification may be expected as early as 24 hours as the surface disturbance moves westward toward or under a high pressure cell or ridge at the 300-200mb level. This superposition relationship of the long wave and easterly wave with the ITC was fundamentally what Deppermann recognized in his triple point theory.

Failure to intensify and subsequent dissipation may be forecast should a low cell or flat pressure field exist at the upper levels when all other relationships as cited above remain the same. Complete deterioration of the depression or loss of convergence pattern associated with it follows and is accompanied by excessive precipitation W of the fracture area. Abnormal rains of one inch per hour or more will occur within the 24 to 30-hour period following with a minimum rainfall of 10 to 16 inches. There were no examples of this sequence of events during 1962.

Future development into a tropical storm being capped by a high level anticyclone is an excellent forecast. Further intensification to a typhoon will be dependent on forecasting a 700mb minimum temperature of 15°C and height of 9900 ft, and a minimum surface pressure of 990mb. The superposition and fracture of long waves with major easterly waves and the intensification under a high level anticyclone verified for approximately 88% of the 1962 typhoons.

Riehl's classical concepts in considering the formative stage also establish the criterion that at time of fracture, the long waves will be slowly progressive or be just starting to move eastward after a stationary period. It has been concluded from the 1962 season that formation will not take place while the long waves are stationary, retrogressive, or fast-moving.

Minor easterly waves are also perturbations in the tropical easterlies but without the associated weather patterns of the major ones. The minor easterly waves consist of a wind shift on the time-cross sections and can be identified by surface isobaric analysis. These waves bear close observance, as major easterly waves can develop on the minor's intensification.

Major and minor easterly waves, as they transit from the Marshall Islands to the South China Sea, will follow each other in random order at a mean speed of 10 kts with a minimum separation of 30 hours or multiples thereof. Bryson (4) identified these perturbation sequences initially in the Guam Symposium of October 1945. Variances toward the seasonal minimum number of perturbation passages at Guam are directly related to the strength and position of the Pacific high pressure cell or ridge.

The ITC also plays an important part in a typhoon's formative stage. Its junction with an easterly wave, identified as the junction vortex, is the initial tropical cyclone from which a tropical depression can be put in warning status. The ITC is a belt of equatorial air, with a normal width of approximately 15° in latitude in the Western Pacific Ocean, which separates the NE trades of the Northern Hemisphere from the SE trades of the Southern Hemisphere. Its boundaries appear as two quasi-parallel lines of intermittent convergence and divergence, which areas vary alternately in length from 300 to 800 miles. This equatorial zone will normally be an area of divergence, but when the width is 10° or less, continuous convergence is expected across the zone. I have, in past years, had soundings which showed a higher moisture content in the equatorial air than that of tropical air at corresponding elevations especially during the formative stage of a tropical storm.

Seasonal effects are observed in the penetration of the northern boundaries of the ITC (NITC) (9) into the Northern Hemisphere. During the summer season, the boundary can surge northward to 25N in the Philippine Sea during low circulation index situations and 15N in high index situations. At these northern positions, the NITC convergence line will dissipate within two days and a new boundary will form in the area between 2N and 5N. This action will follow the movement of long waves from the Asiatic mainland eastward toward Wake Island. Caution is cited for the possible development of the junction vortices in the NITC during these surges, i.e., Typhoon IDA, 1961. During the winter months, the NITC is observed at 2N or S, at the longitude of Guam, as a quasi-stationary system. The convergent boundary of the ITC in the Southern Hemisphere (SITC) (9) has not been ascertained due to lack of data for analysis.

The preceding description of the ITC, major and minor easterly waves, and junction vortex and the inter-action with the long waves brings us to the 48-hour period after fracture time. During this period, the NITC is observed to break or "gate" into the center of the storm. The word, "gate," is used to provide a descriptive term to portray the break of the NITC by opening the flow of high moisture content equatorial air for future development. Also it explains the associated high southerly winds specifically observed in the formation of Typhoons GEORGIA, HOPE, WANDA, GILDA and KAREN in 1962. This phenomenon is illustrated best by streamline analysis at 700mb and below. In addition, special reconnaissance can establish whether the junction vortex or an embedded vortex to the N in the same easterly wave actually becomes the storm. The embedded vortex is the most common case with development expected from 3 to 5 degrees N of the junction vortex. This occurrence is observed in the Philippine Sea and to the SE of the Marianas with a sudden onset of southerly flow into the southern and eastern quadrants of the storm after "gating" time. When "gating" takes place near the time of passage of Guam, increased convective activity continues for an additional 2 or 3 days, with approximately 35 kt surface winds and gusts to 55 kts beginning on the second day.

A higher frequency of synoptic fixed track aerial reconnaissance in several previous years concerning the junction vortex has shown the following analogy and the observed result.

1. Weak or open northern quadrants with strong convergent southern quadrants will upon fracture indicate development of the embedded vortex with subsequent "gating."

2. Strong convergent northern quadrants with weak or

open southern quadrants will upon fracture indicate development of the junction vortex alone, which will normally not exceed tropical storm warning status, if it should intensify.

The junction vortex is initially the stronger and masks the circulation of the embedded vortex to its N. After fracture, the embedded vortex normally develops rapidly at the expense of the junction vortex, except as noted in the preceding paragraph, giving the impression that the storm has suddenly jumped 200 to 300 mi to the N. When final development is ascertained to be from an embedded vortex, the postanalysis track is in error if drawn by connecting the embedded vortex positions with those of the junction vortex. Two tracks should be drawn, if the points can be substantiated, and be connected by a dashed N-S line to show visually this formation phenomenon at the established "gating" time.

IV. Movement of Tropical Cyclones

The initial movement of tropical cyclones in the easterlies has been theoretically developed by Yeh (18) and verified by storm tracks fixed by reconnaissance. Yeh's oscillatory track for tropical cyclones has been a valuable contribution to forecasting movement. Empirical verification of the expected oscillations about the mean tracks in the Pacific gave curves of one degree amplitude with a period of 24 to 40 hours as compared with Yeh's maximum of two-thirds of a degree and 48 to 60 hours in the Atlantic. Maximum amplitudes are found with incipient storms, the amplitudes decrease as the tropical cyclones intensify, recurve, and/or increase their speed of movement.

Fujiwhara effect between two tropical cyclones classically occurred last in 1961 with Typhoons HELEN and IDA. Partial Fujiwhara movement during 1962 occurred with GILDA and IVY, and EMMA and FREDA.

When the long wave progresses E of the Marianas to the vicinity of Marcus and Wake Islands, it leaves a weak pressure gradient over the Philippine Sea between 15N and 25N. This affects the initial movement of typhoons by permitting the storm to move directly N as the subtropical ridge line reforms. Such a synoptic situation has been repeatedly noted during the 48 hours subsequent to fracture in the vicinity of Guam, when a storm is located at approximately 15N. Storms S of this latitude will normally not be affected, but the others are subjected to premature recurvature and being reversed in direction as the ridge line rapidly reforms. Typhoon KAREN, 1962, was an excellent example of this movement pattern.

Persistent movement of tropical cyclones in low latitudes is wholly dependent on the criteria previously set forth with the long waves and the latitudinal position of the cyclone itself. Application of these relationships are normally by inspection, and the resultant forecasts are straightforward.

Recurvature of tropical cyclones (3) N of 15N is always directly associated with the long waves as outlined below.

1. Tropical cyclones will recurve into stationary or slowly progressive long waves.

2. Tropical cyclones will not recurve into fast-moving long waves as the period is too short to allow the storm to be dominated by its influence.

3. Retrogression of the long wave normally does not permit a tropical cyclone to recurve, but it will accelerate the tropical cyclone westward as the anticyclone to the E spreads rapidly westward, i.e., Typhoon GILDA, 1962.

4. Tropical cyclones will not recurve into minor troughs, but they will cause a temporary increase in the northward component of the storm's movement.

Yeh enters the picture again at this point with his four theoretical recurvature trajectories. The four equidistant positions along one segment of the oscillatory track produced only one valid trajectory which occurred after the anticyclonic portion of its track.

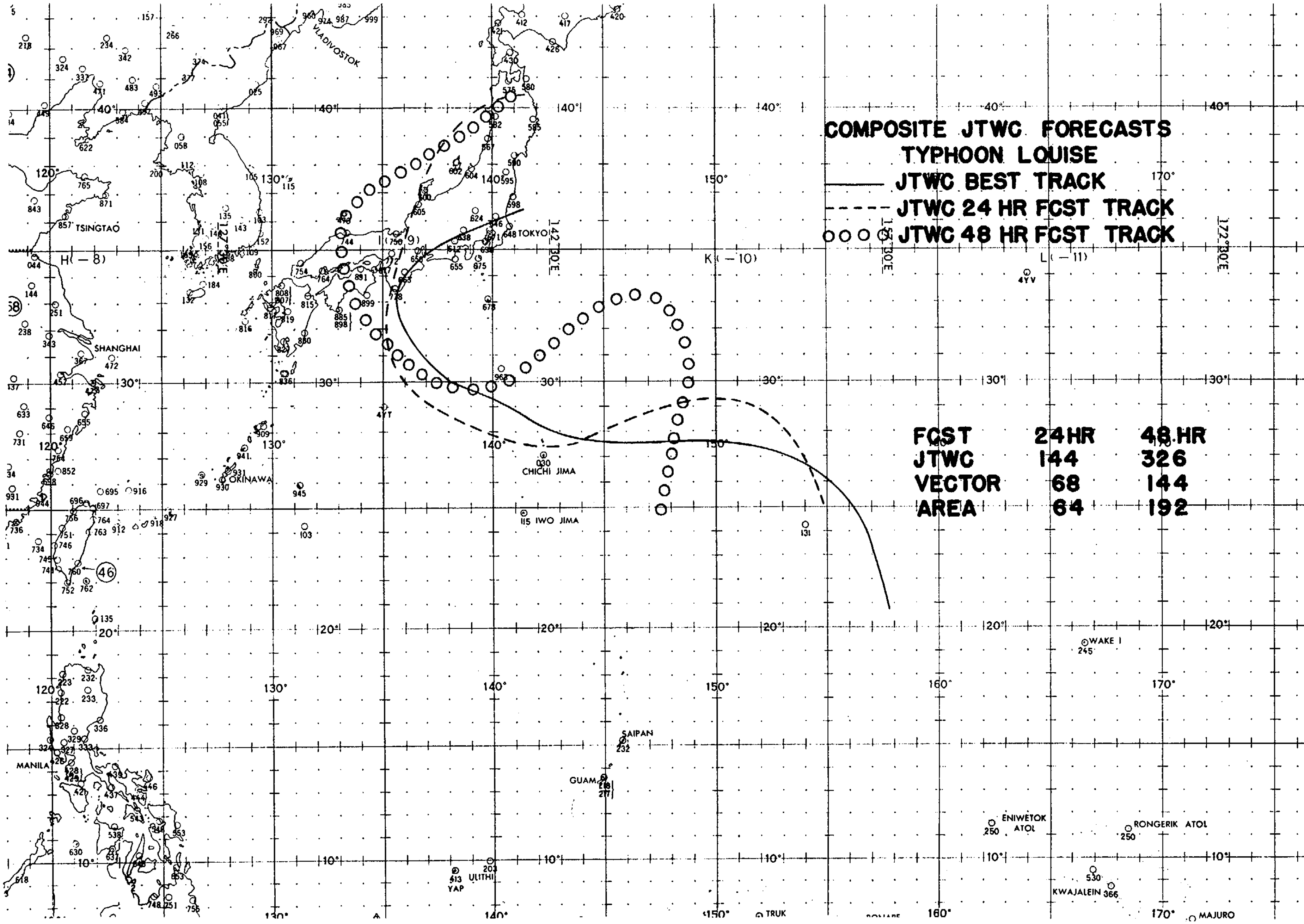
The zonal wind (3) conditions for recurvature, favorable and unfavorable, but not available for use in the

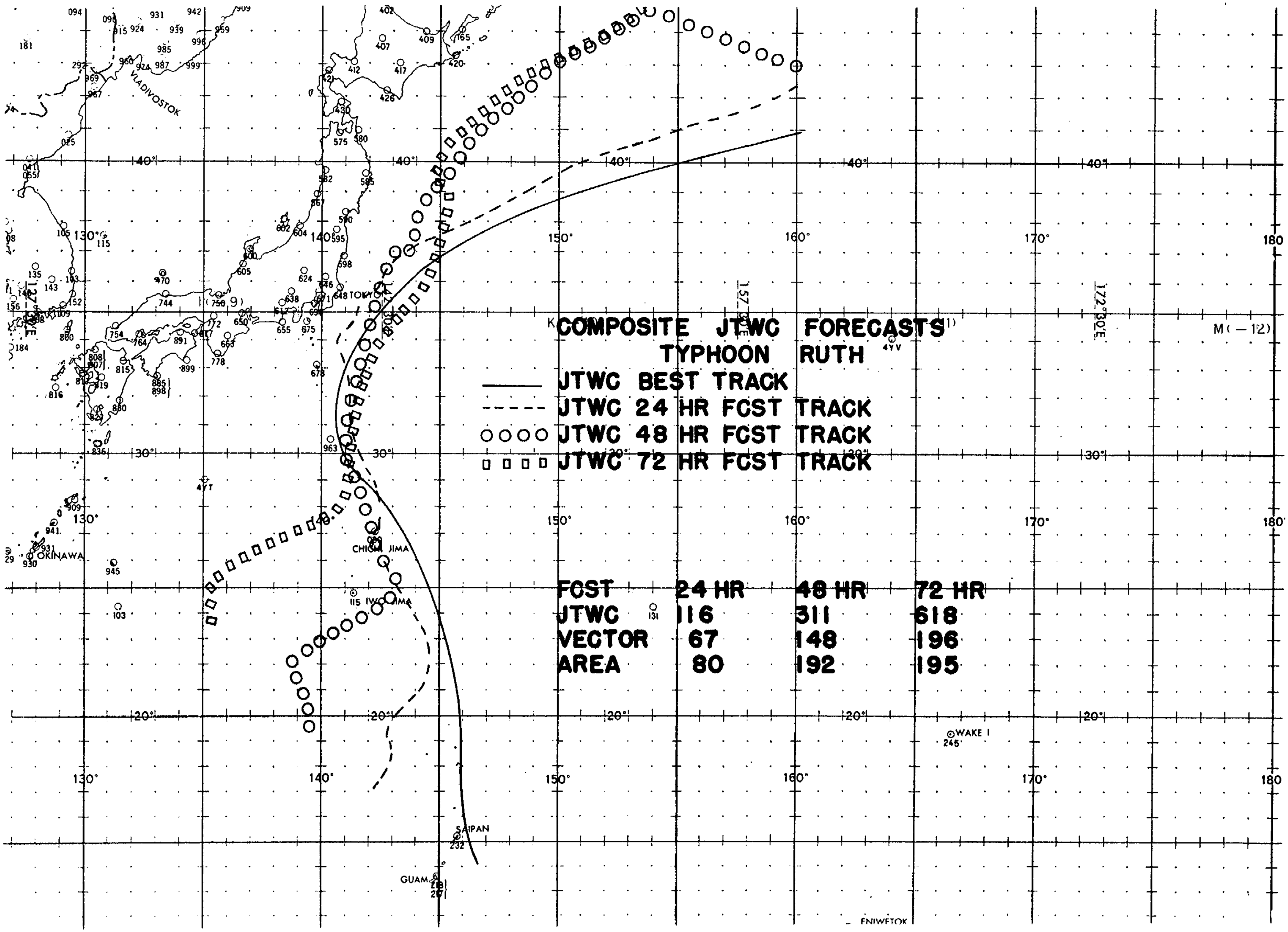
1961 and 1962 seasons.

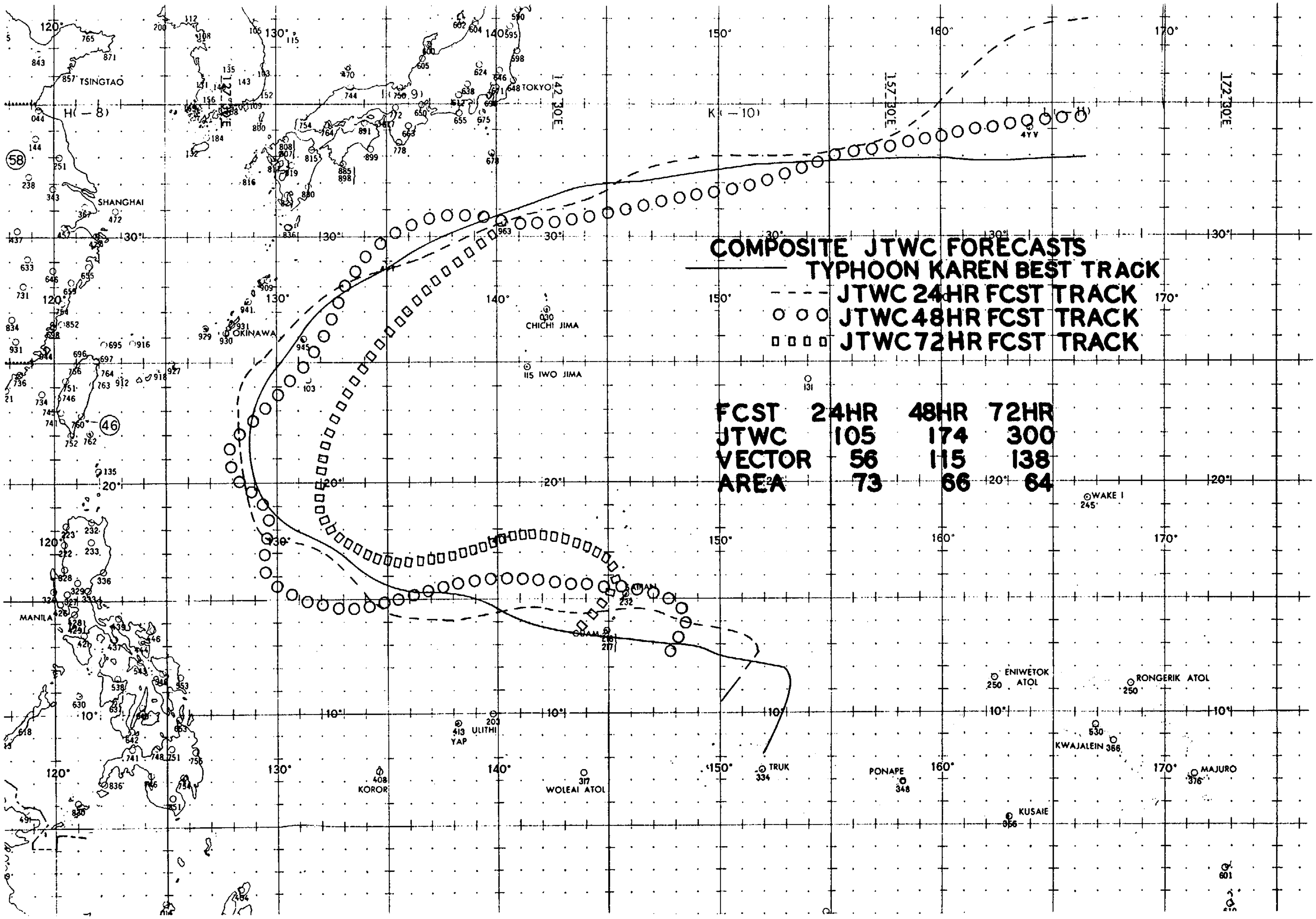
Operationally, 72-hour forecasts were made internally by JTWC and based on 120 cases provided an error of 476 MI, which was within the same tolerance of error as the 24 and 48-hour forecasts. When warning responsibility for Typhoon KAREN was passed to Fuchu Air Force Weather Central, Japan, JTWC's six day forecast track was included. It averaged a degree inside the "best" track on postanalysis. Extended forecasts should be the ultimate goal of every warning center. With them, consumers can make adequate securing and evacuation plans. KAREN's initial 72-hour warning for Guam was JTWC's best example of this capability.

A new briefing system is proposed for the customer to basically portray the "best" track with the actual 24, 48, and 72-hour tracked positions and show the actual areas warned by these categories of forecast times. Two approximation systems have been selected for 3 forecast times: first, perpendicular vectors at 60 mile intervals as positive values whether left or right of "best" track were averaged; and secondly, by area which is resolved as a scalar value from the "best" track. Typhoons LOUISE, RUTH and KAREN are so depicted by the following charts.

Acknowledgment: I extend my appreciation to the members of the Typhoon Post-Analysis Board and the Joint Typhoon Warning Center with whom I was associated during my two tours on Guam, 1950-51 and 1961-62, respectively, for their typhoon forecasts, cooperation, and investigations in support of this important meteorological and operational program. I wish to add special mention for the weather reconnaissance squadrons assigned the hazardous mission to penetrate or track typhoons routinely on a fixed schedule. Captain W. J. Kotsch, USN, Commanding Officer FWC/JTWC, has my sincere thanks for his faith, loyalty, and autonomy in my direction of JTWC.


COMPOSITE JTWC FORECASTS
TYPHOON LOUISE
JTWC BEST TRACK
JTWC 24 HR FCST TRACK
JTWC 48 HR FCST TRACK
FCST 24 HR 48 HR
JTWC 144 326
VECTOR 68 144
AREA 64 192
VLADIVOSTOK
TSINGTAO
SHANGHAI
TOKYO
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
SAIPAN
GUAM
WAKE I
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
YAP
ULITHI
TRUK
MAJURO


COMPOSITE JTWC FORECASTS
TYPHOON RUTH
JTWC BEST TRACK
JTWC 24 HR FCST TRACK
JTWC 48 HR FCST TRACK
JTWC 72 HR FCST TRACK
FCST 24 HR 48 HR 72 HR
JTWC 116 311 618
VECTOR 67 148 196
AREA 80 192 195
VLADIVOSTOK
TOKYO
CHICHI JIMA
IWO JIMA
OKINAWA
SAIPAN
GUAM
WAKE I
ENIWETOK
40°
30°
20°
130°
140°
150°
160°
170°
180


COMPOSITE JTWC FORECASTS
TYPHOON KAREN BEST TRACK
JTWC 24HR FCST TRACK
JTWC 48HR FCST TRACK
JTWC 72HR FCST TRACK
FCST 24HR 48HR 72HR
JTWC 105 174 300
VECTOR 56 115 138
AREA 73 66 64
TSINGTAO
SHANGHAI
TOKYO
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
GUAM
SAIPAN
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I

EVALUATION OF STATISTICAL AND COMPUTER TYPHOON FORECASTING PROCEDURES

by

Capt William D. Roper, USAF

Three techniques, the Arakawa, Miller-Moore and Fleet Numerical Weather Facility Computer forecasts from Monterey, California, were used as aids to assist the Joint Typhoon Warning Center (JTWC) in determining tracks and speeds of movement of typhoons during the 1962 season. The development of the forecasting methods will not be shown in this report; however, one may refer to the 1961 Annual Typhoon Report for background material on the Arakawa method (17) and the re-evaluation of the constants in the regression equations for the Miller-Moore, which was originally developed for hurricanes in the Atlantic (8). Tilden's report at the 1960 Typhoon Symposium has basic information on Miller-Moore's principle (16).

The Arakawa method uses surface parameters to give 24 and 48-hour forecast positions every six hours as well as central pressure forecasts. The Miller-Moore system utilizes 700mb data to give 24-hour forecast positions every 12 hours. FNWF Computer model uses 500mb data supplemented by JTWC's Bulletin positions of the storm's center to give 6, 12, 18, 24, 36, 48 and 72-hour forecast positions every six hours. The synoptic time for upper level winds is used as the base time for the beginning of the forecast periods; thus, at 0000Z and 1200Z, each forecast interval is decreased by 12 hours.

To evaluate the three techniques in comparison with JTWC's forecasts, three typhoons were selected as being representative of the 1962 season. The first and last typhoons and one during the middle part of the year were chosen. The best track of each storm is given and the 24 and 48-hour forecast track for each method is shown as well as the mean error for the typhoon in nautical miles. A mean best track of the recurving typhoons, of which there were 17 during 1962, and a mean best track of the non-recurving typhoons, of which there were 7, is presented with the mean forecasts of each method used as well as

JTWC's prognosis. The vector error of the Arakawa, Miller-Moore, FNWF and JTWC forecasts for all typhoons is tabulated. It should be pointed out that JTWC's forecast is an operational one, which means that in regard to the other systems, our forecast, even though it is valid for the same time periods, is prepared before the data to compute their forecasts is plotted or analyzed.

A 24-hour forecast track is obtained by connecting successive 24-hour forecast positions every six hours. Comparing GEORGIA's best track with Arakawa's 24-hour forecast track (Chart 1), one can see where the best result occurred. The original forecast fell to the N of track; however, no excessive error is shown in relation to variance from the best track. The forecast of GEORGIA's recurvature lagged by nearly 5 degrees. This tends to show the amount of persistence of movement built into the system. After recurvature, GEORGIA moved consistently to the NE, and the Arakawa forecast did quite well. Then near 27N, GEORGIA began to move northward and accelerate. Once again, persistence of movement associated with Arakawa's method came into consideration, and since GEORGIA's speed of movement was near 40 kts in this area, large spreading or error of the forecast track occurred. The same trend is shown from the 48-hour forecast track with recurvature forecast to occur near 25N. As GEORGIA began to pull rapidly toward a mid-latitude trough, she became extratropical before the 48-hour forecast could indicate a northward movement.

The Miller-Moore method and JTWC's forecasts show very similar results in that each lagged in recurvature and both failed to forecast the more northerly movement of GEORGIA near 27N, initially, in varying degrees (Charts 2 & 3). During the beginning of GEORGIA as she was performing a cyclonic loop, both Miller-Moore and JTWC indicated a slow WNW movement. No forecasts were received from FNWF for GEORGIA as their program did not begin until 1 July 1962.

In summary, the largest errors for all systems of forecast occurred after GEORGIA accelerated and changed direction from NE to an almost straight N path. The other errors were made during recurvature and at the beginning when she performed the cyclonic loop. GEORGIA was the first typhoon of 1962 and existed in tropical warning status for 7½ calendar days between 161200Z and 240000Z April. She existed as a typhoon for 5 3/4 calendar days.

AMY, an example of a recurving storm, existed in tropical warning status from 290600Z August to 080000Z September, or for 9 3/4 calendar days of which she remained in typhoon intensity for 6¼ days. The areas affected by the forecast track of AMY for the Arakawa, Miller-Moore and JTWC are almost identical (Charts 4, 5 & 7). Originally, AMY followed the forecast tracks to the NW, but as she began to move more westerly, all forecasts fell to the N of the best track. A slight lag on forecasting recurvature is shown; however, in general, the forecast path was very near the best track until dissipation.

FNWF Computer forecast track was good in the beginning, picking up the W trend; however, as AMY began to move NW in the vicinity of Taiwan and recurve, the forecast path became somewhat erratic (Chart 6).

LUCY, the final typhoon of the season, existed in tropical warning status for 6 3/4 calendar days between 250000Z November and 011800Z December, maintained typhoon intensity for 3½ calendar days and was a non-recurving storm. The Arakawa and FNWF forecast tracks follow the best track in an almost exact manner (Charts 8 & 10); however, the Miller-Moore and JTWC forecasts show a tendency to fall to the N of LUCY's actual path (Charts 9 & 11).

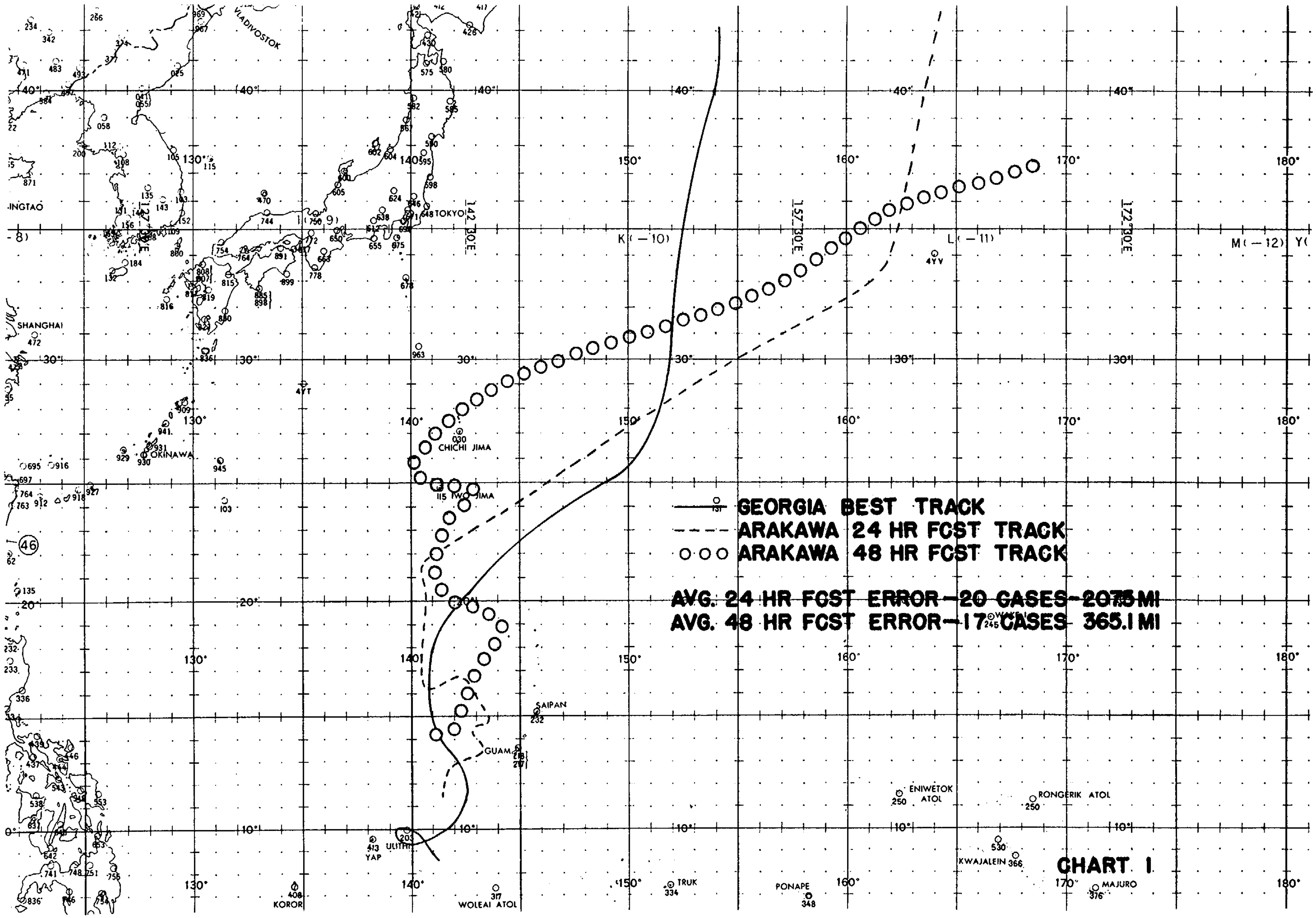
The mean best track for all recurving storms extends between the islands of Truk and Yap, then is bounded by 135E and 140E until 100 mi S of Tokyo, thence NE to 41N (Chart 12). Two points of recurvature are shown, one near 16N and the other near 27N. The mean best track and mean forecast tracks for each method were computed for the recurving storms by averaging all longitudinal positions for each degree of latitude. The closest part of mean forecast track to mean best track of the recurving typhoons is found in the Miller-Moore technique with the two paths very nearly coinciding N of 24N (Chart 14). Some difficulty is noted near the first point of recurvature and at the beginning of the Miller-Moore forecast track. The Arakawa, FNWF and JTWC mean forecasts show a greater variance from the best track during recurvature and by falling N of the actual positions in the beginning (Charts 13, 15 & 16). FNWF forecast is the only system which has a mean track penetrating Japan.

The mean best track and mean forecast tracks for the non-recurving storms was obtained by averaging all latitudinal positions for each degree of longitude. The mean best track extends from just N of Yap Island through the northern part of Luzon, westward to 115E and then drops southwestward into Indo-China near 15N (Chart 12). The Arakawa 24 and 48-hour forecast track is similar to JTWC's in that both forecast too great a N component on the storm's positions, especially E of the Philippines (Charts 17 & 20). This is much more evident on the 48-hour forecast. The best mean forecast tracks for 24 hours is by the Miller-Moore and FNWF Computer model with the latter's 48-hour forecast also showing excellent results (Charts 18 & 19).

In conclusion, the Miller-Moore method was the most accurate aid that JTWC had available for recurving storms with the Arakawa giving the best forecast for non-recurving storms. Weaknesses of all systems are most evident in the beginning and through recurvature. The Miller-Moore and Arakawa rely heavily upon persistence of movement. When the storm is changing direction, accelerating or decelerating, the largest errors occur. Normally, as the storm recurves, both systems fall to the left of track and the forecast speed of movement is excessive. In general, a typhoon that accelerates will cause the Miller-Moore and Arakawa forecasts to be short of the existing position while one that decelerates will cause both methods to overshoot the actual position. By looking at the mean error of the recurvature vs. the non-recurvature storms, one can see that the recurving storms prove to be the most difficult for all forecasting methods. The excessive number of recurving storms during the past season explains why the mean forecast error of JTWC for 1962 was higher than in 1961. Eleven recurving and 9 non-recurving typhoons occurred during the 1961 season vs. 17 and 7, respectively, in 1962.

Another point of interest is that FNWF track forecasts for the non-recurving storms, even though at lower latitudes, was considerably better than the recurving storms in higher latitudes. This, in part, could be caused by the fact that the non-recurving storms, on the average, were not nearly as strong or well developed in the vertical. Correspondence during the year from Monterey indicated that their model worked best when the storm's closed circulation was weak at the 300mb level. The forecast speed of movement of the typhoons was, as a whole, much slower than the verified speed. LUCY can be cited as an example of this fact. Excellent direction forecast is evident, yet the average forecast error for 24 and 48 hours was 208 MI and 476 MI, respectively.

The greatest variance in track forecast of all methods occurred, for both recurving and non-recurving storms, in the area bounded by 15N and 25N, 130E and 140E. This would indicate the need for a new forecasting technique to determine whether a typhoon is going to recurve or continue on a more westerly track early in the storm's beginning phase. At the present time, JTWC is considering the feasibility of developing an analogue system based on climatology to assist the forecaster in steering typhoons below 20N.


GEORGIA BEST TRACK
ARAKAWA 24 HR FCST TRACK
ARAKAWA 48 HR FCST TRACK
AVG. 24 HR FCST ERROR—20 CASES—207.5 MI
AVG. 48 HR FCST ERROR—17 CASES 365.1 MI
CHART I

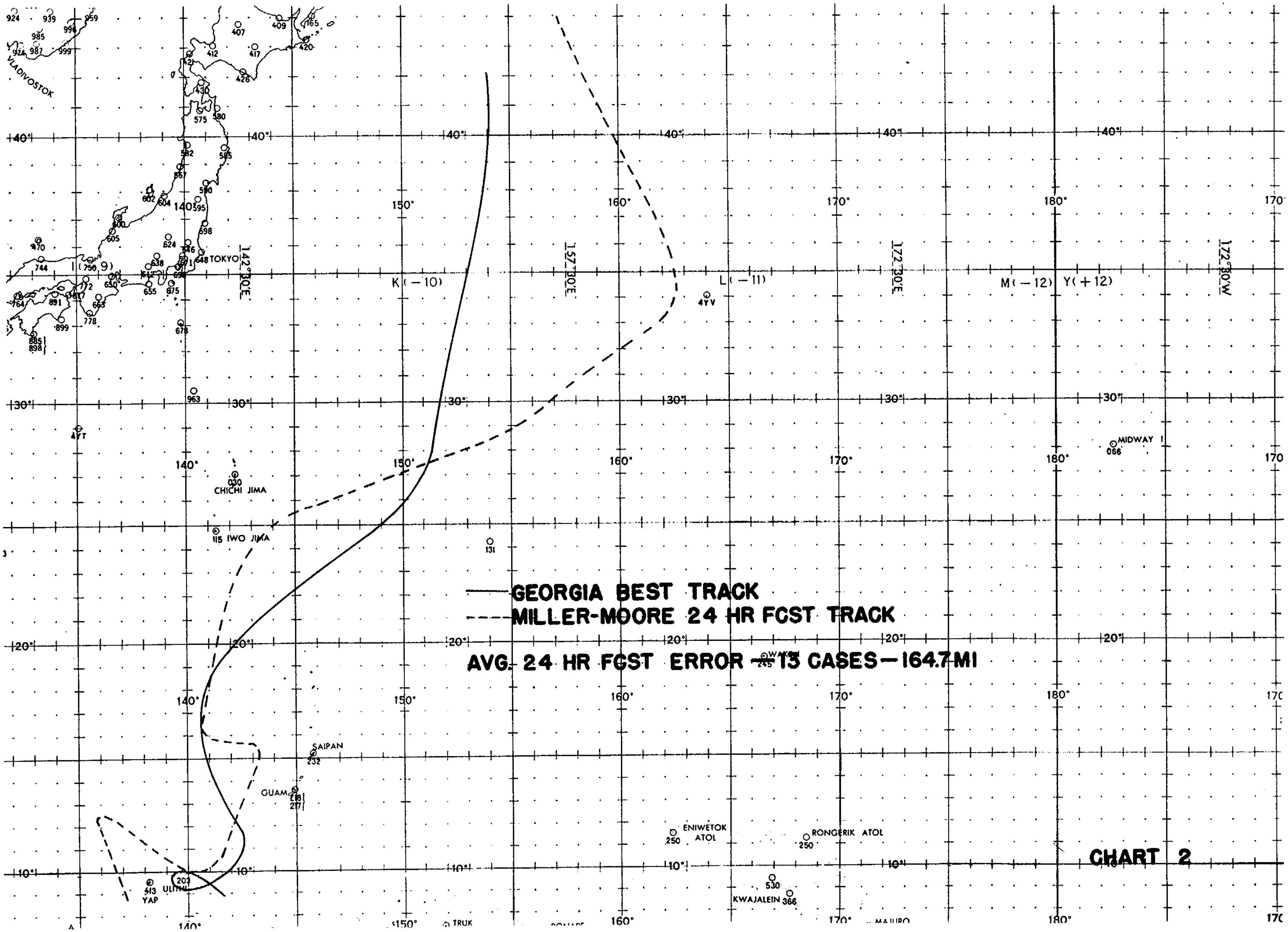
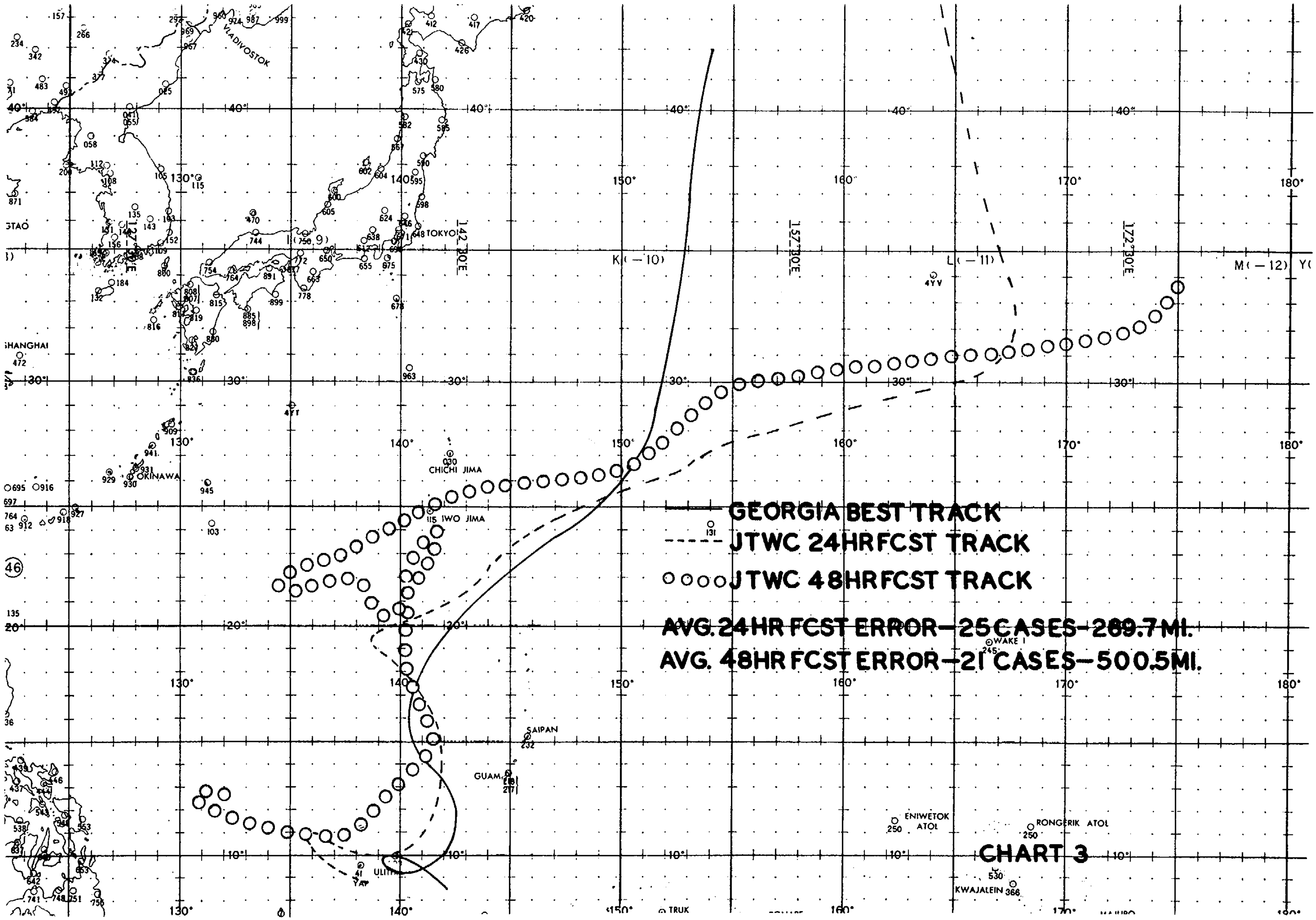

GEORGIA BEST TRACK
MILLER-MOORE 24 HR FCST TRACK
AVG. 24 HR FCST ERROR - 13 CASES - 164.7 MI
VLADIVOSTOK
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MIDWAY I
TRUK
MAJURO
K(-10)
L(-11)
M(-12) Y(+12)
142°30'E
157°30'E
172°30'E
172°30'W

CHART 2


GEORGIA BEST TRACK
JTWC 24HR FCST TRACK
JTWC 48HR FCST TRACK
AVG. 24HR FCST ERROR—25 CASES—289.7 MI.
AVG. 48HR FCST ERROR—21 CASES—500.5 MI.
CHART 3
VLADIVOSTOK
TOKYO
SHANGHAI
OKINAWA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
WAKE I
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
TRUK

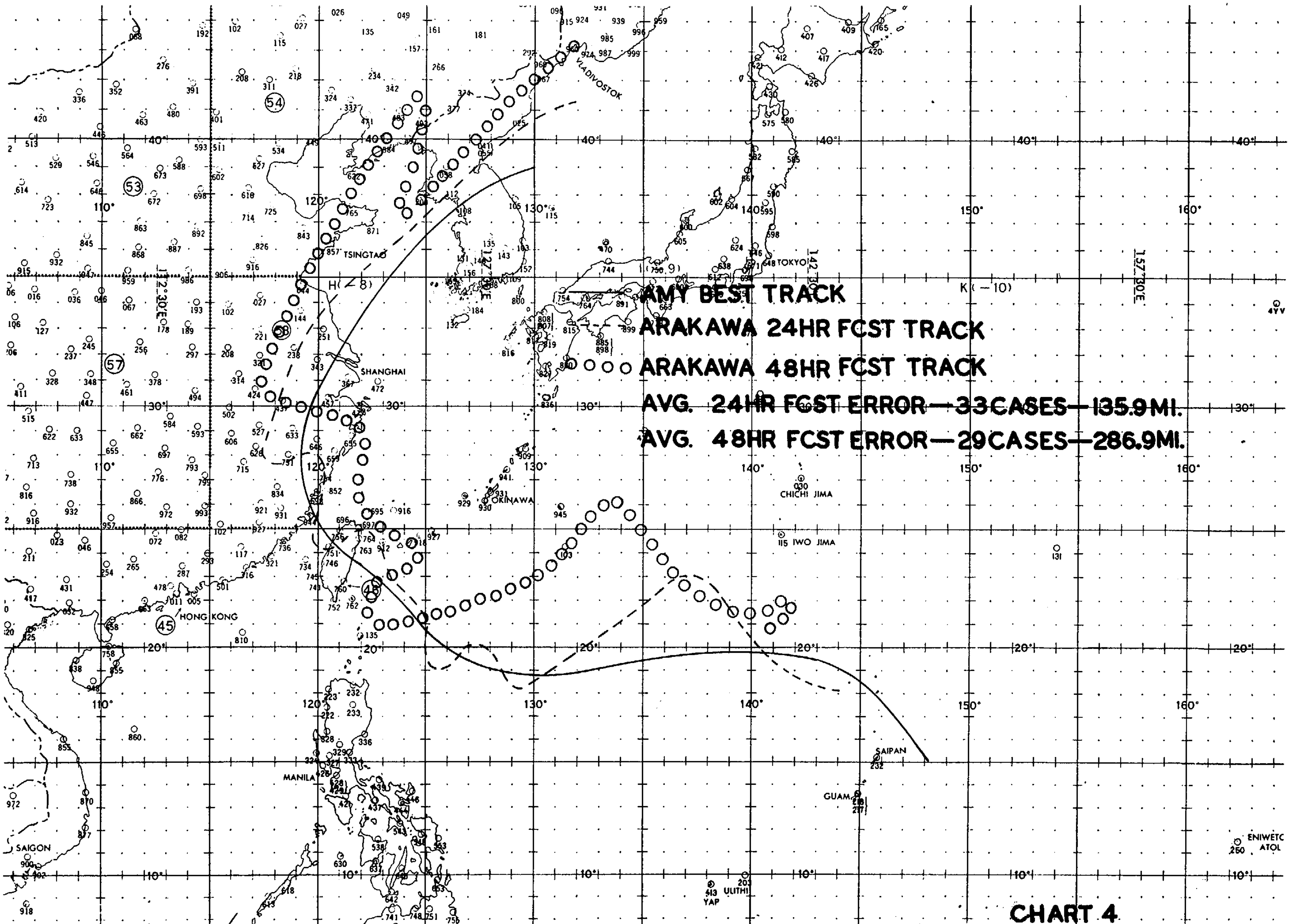
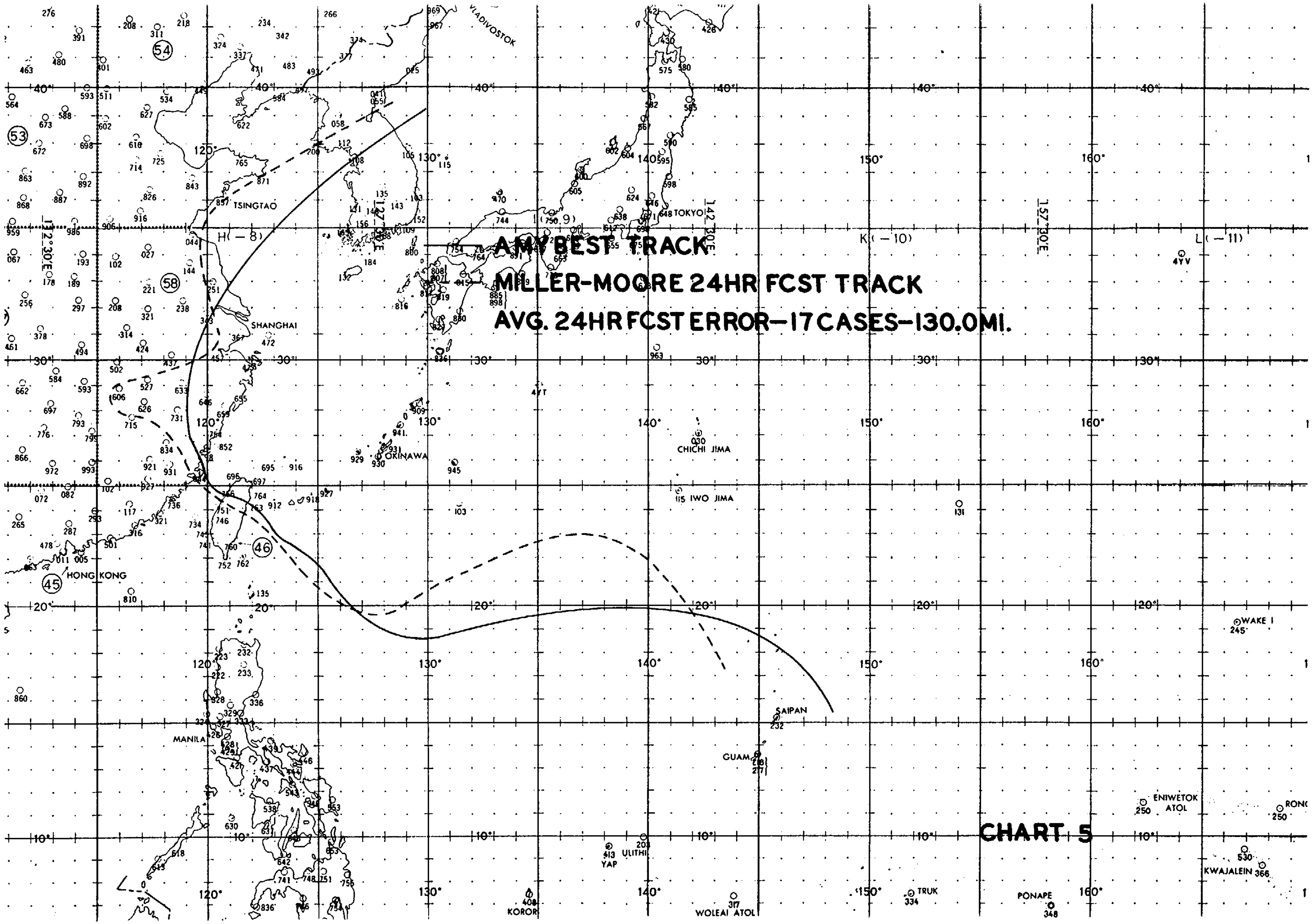
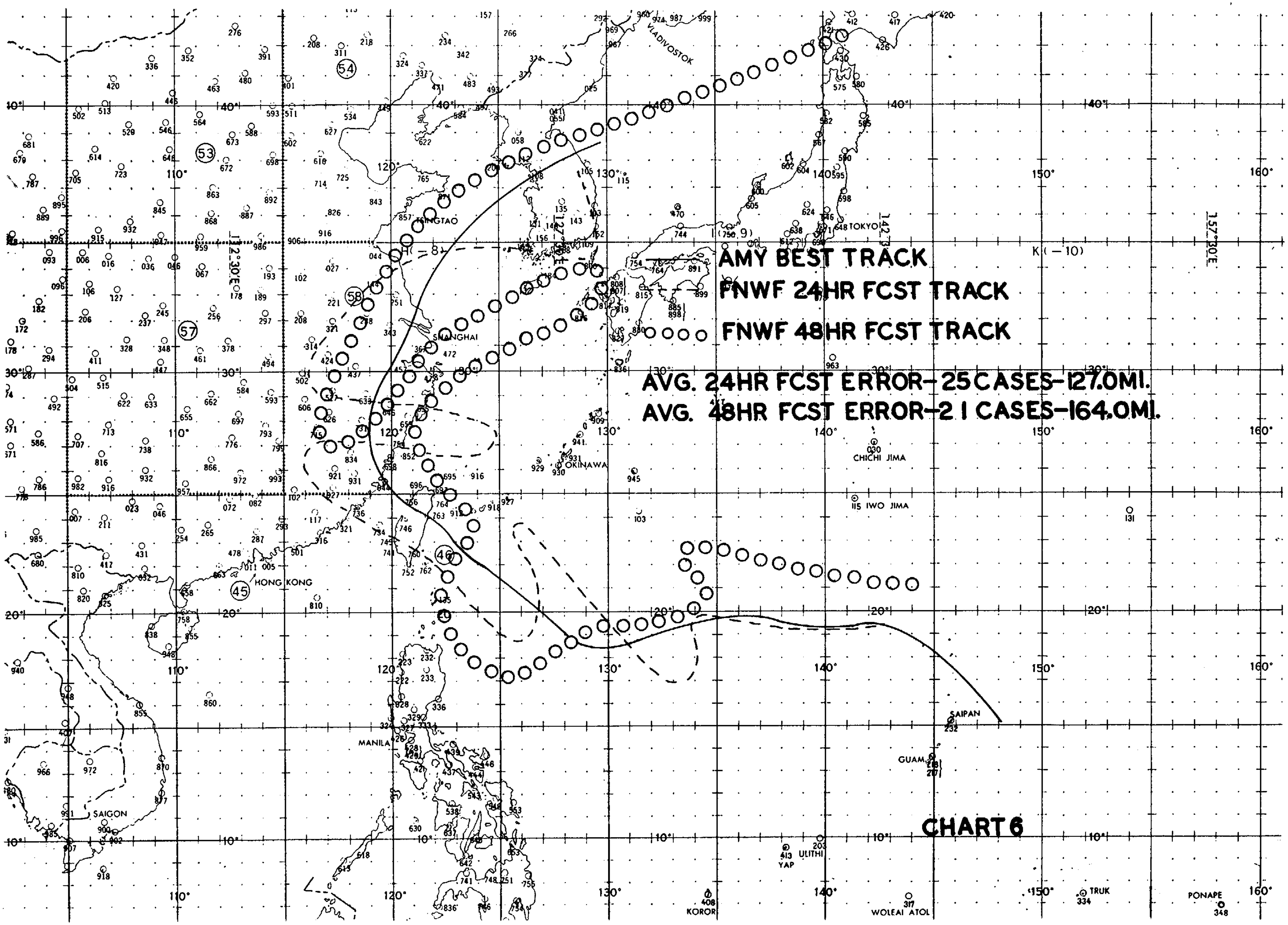
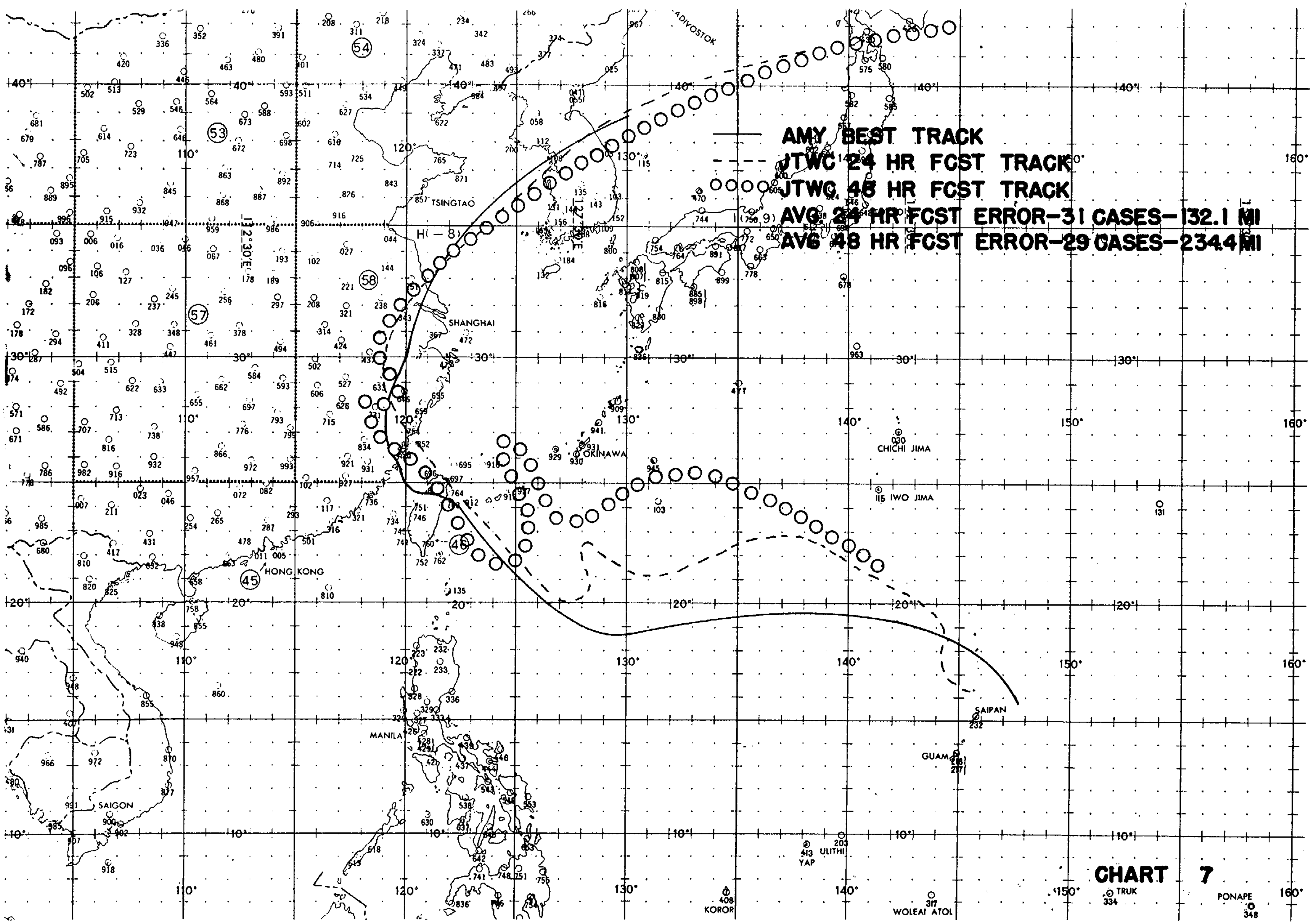
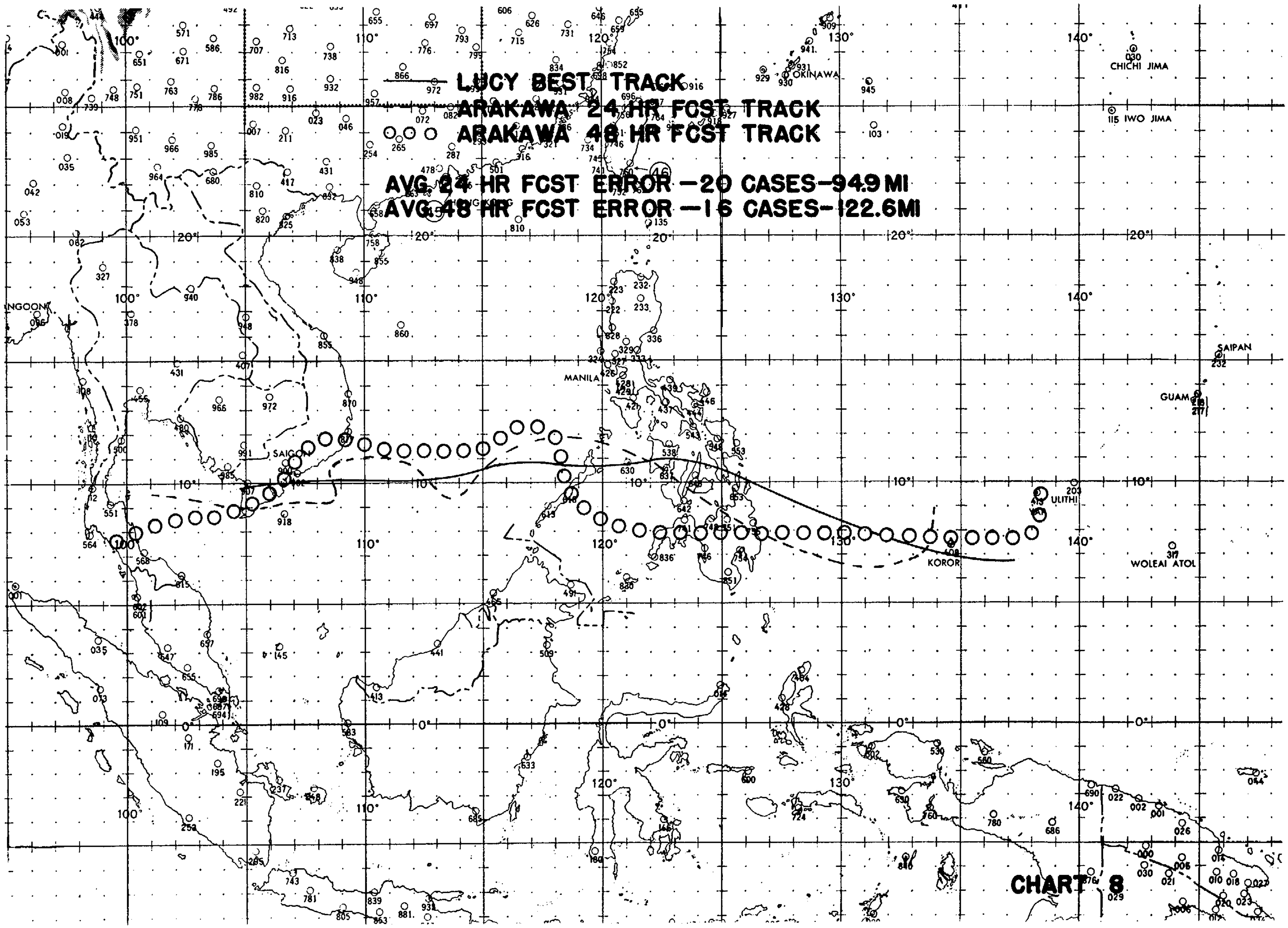

AMY BEST TRACK
ARAKAWA 24HR FCST TRACK
ARAKAWA 48HR FCST TRACK
AVG. 24HR FCST ERROR—33CASES—135.9MI.
AVG. 48HR FCST ERROR—29CASES—286.9MI.
VLADIVOSTOK
TSINGTAO
TOKYO
SHANGHAI
OKINAWA
CHICHI JIMA
IWO JIMA
HONG KONG
MANILA
SAIPAN
GUAM
SAIGON
ULITHI
YAP
ENIWETOK ATOL

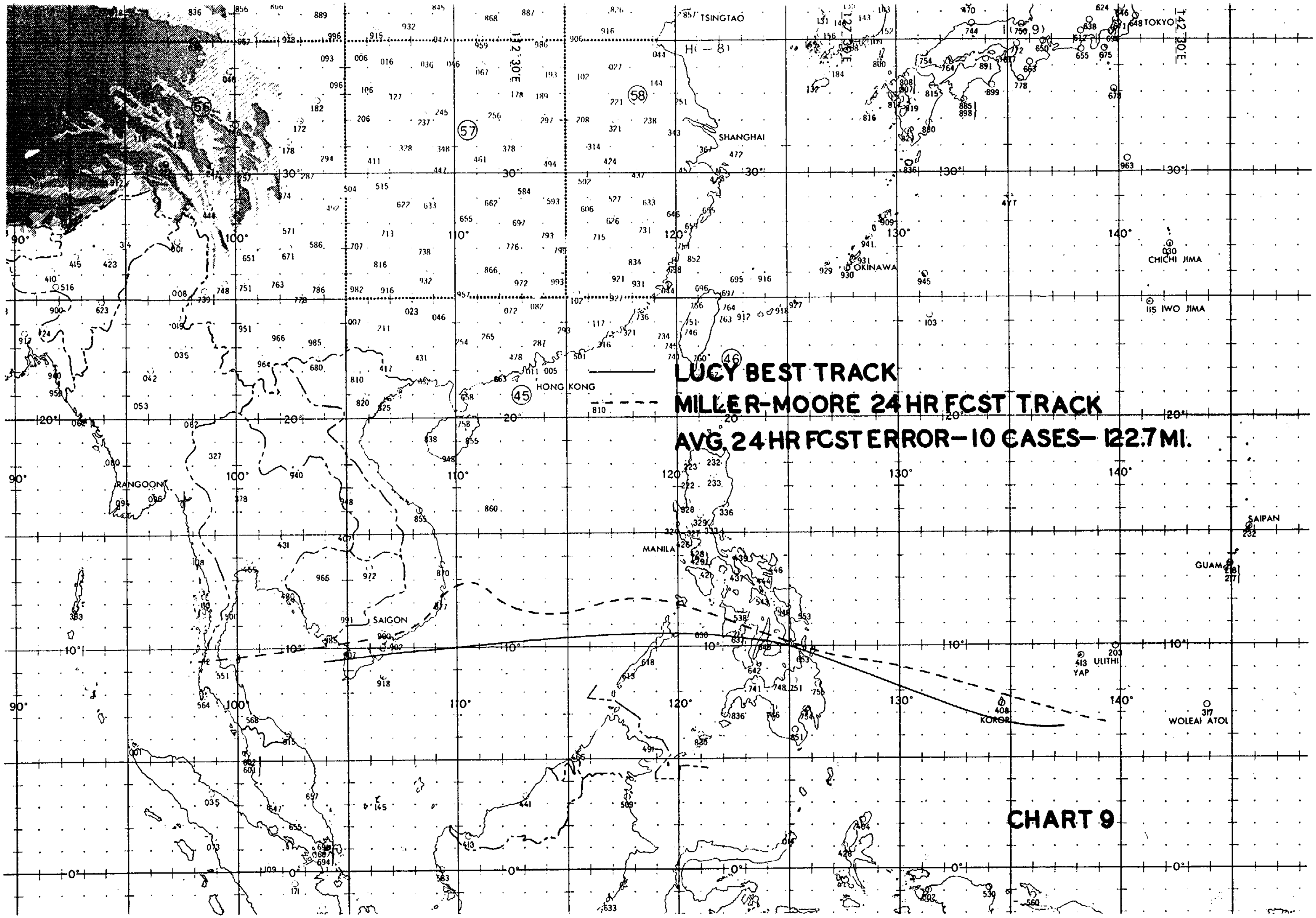
CHART 4

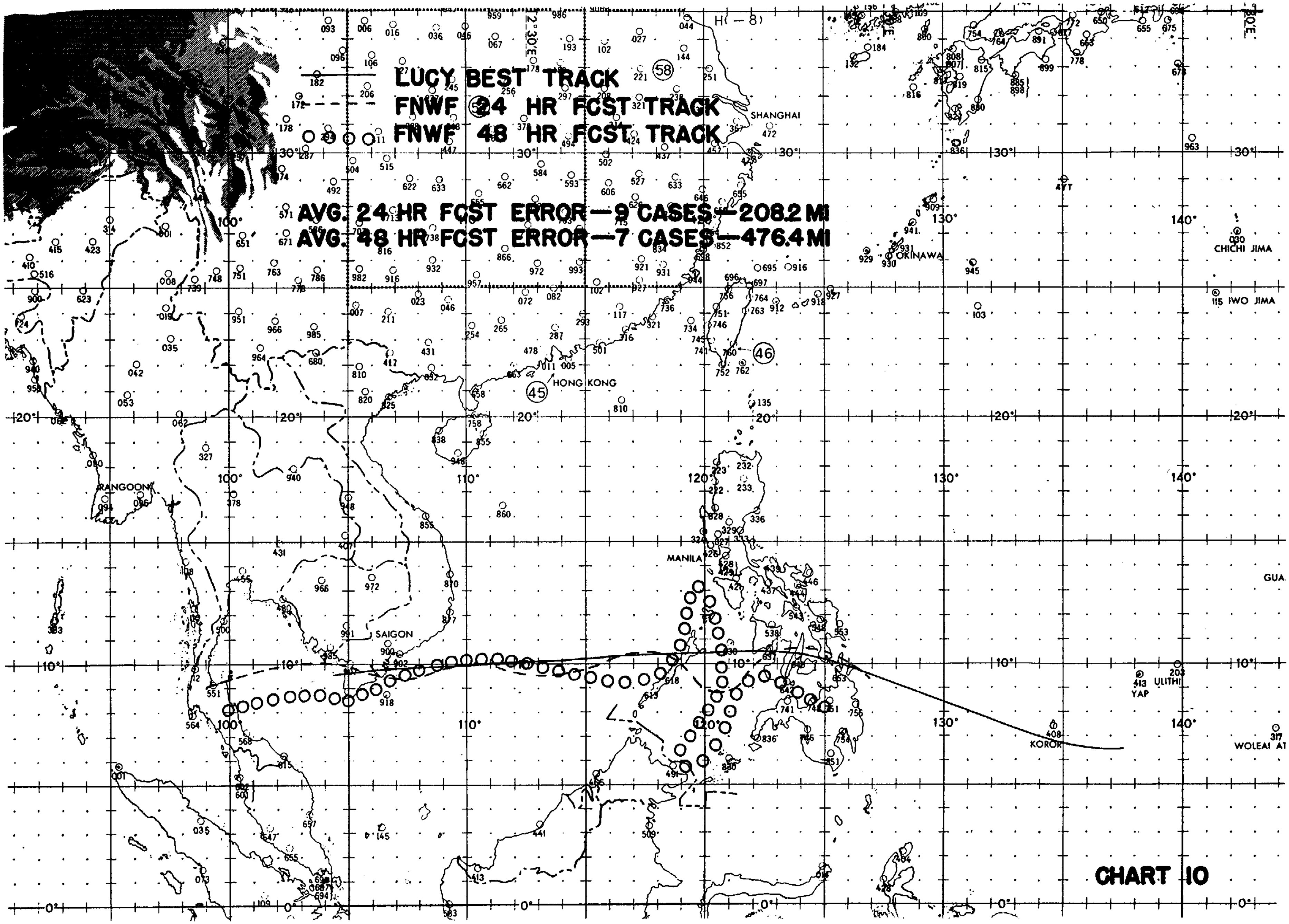

AMY BEST TRACK
MILLER-MOORE 24HR FCST TRACK
AVG. 24HR FCST ERROR—17 CASES—130.0MI.
CHART 5
VLADIVOSTOK
TSINGTAO
SHANGHAI
HONG KONG
MANILA
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
ENIWETOK ATOL
KWAJALEIN
WAKE I

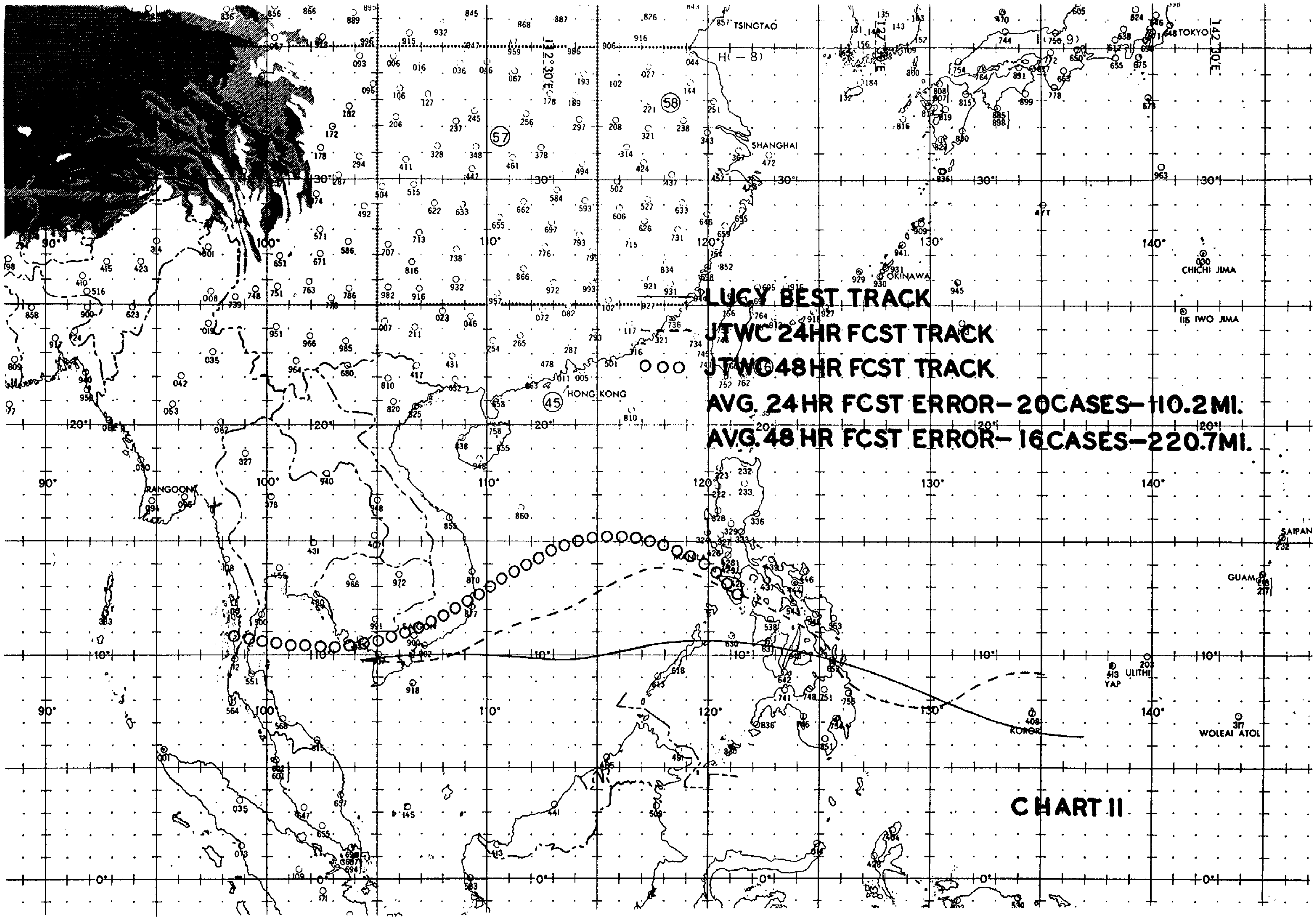

AMY BEST TRACK
FNWF 24HR FCST TRACK
FNWF 48HR FCST TRACK
AVG. 24HR FCST ERROR- 25 CASES-127.0MI.
AVG. 48HR FCST ERROR-21 CASES-164.0MI.
CHART 6
VLADIVOSTOK
TSINGTAO
SHANGHAI
TOKYO
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
SAIGON
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE

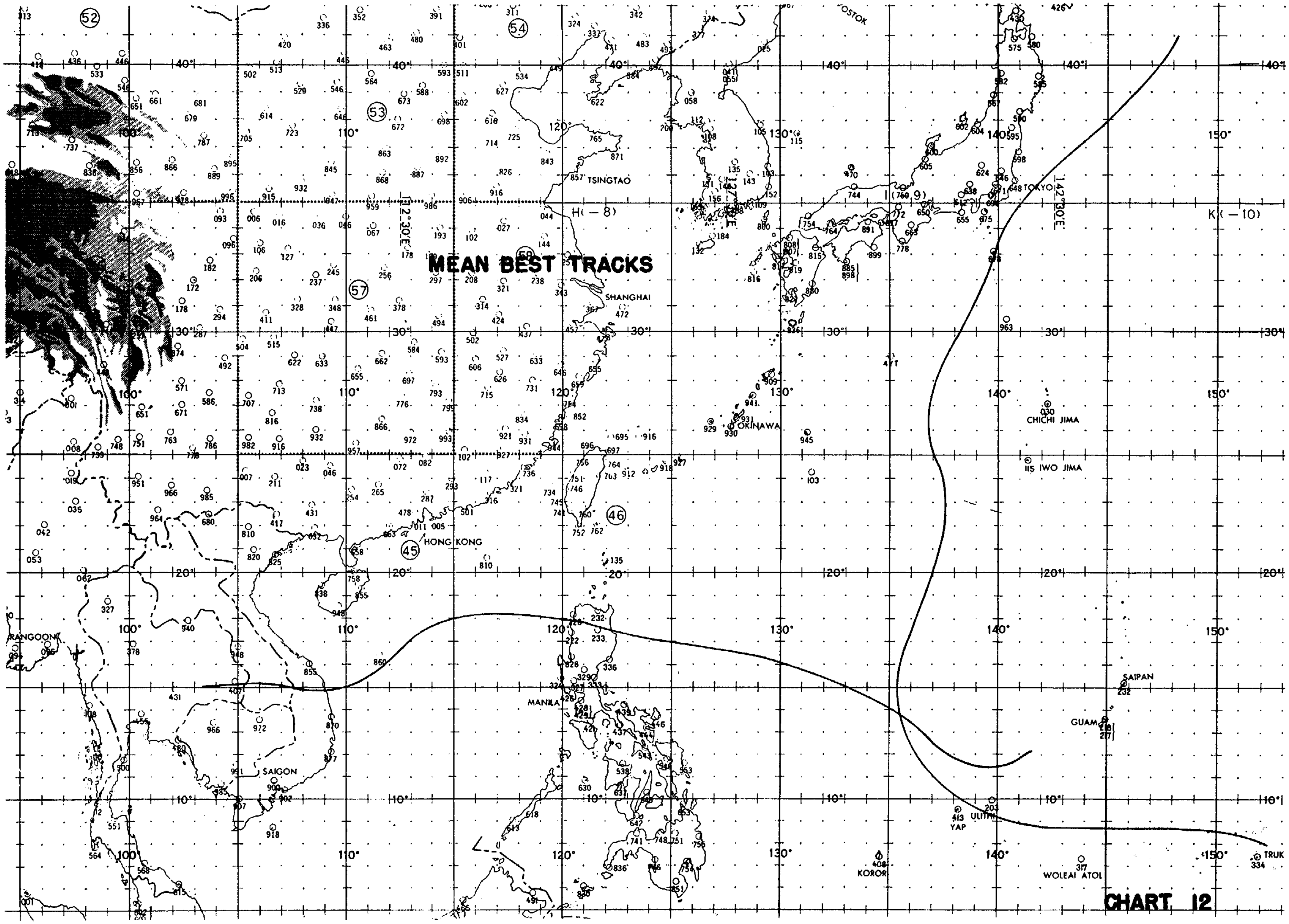

AMY BEST TRACK
JTWC 24 HR FCST TRACK
JTWC 48 HR FCST TRACK
AVG 24 HR FCST ERROR-31 CASES-132.1 MI
AVG 48 HR FCST ERROR-29 CASES-234.4 MI
CHART 7
TSINGTAO
SHANGHAI
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
SAIGON
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE


LUCY BEST TRACK
ARAKAWA 24 HR FCST TRACK
ARAKAWA 48 HR FCST TRACK
AVG 24 HR FCST ERROR -20 CASES-94.9 MI
AVG 48 HR FCST ERROR -16 CASES-122.6MI
CHICHI JIMA
IWO JIMA
OKINAWA
MANILA
SAIGON
ULITHI
KOROR
SAIPAN
GUAM
WOLEAI ATOL
CHART 8


LUCY BEST TRACK
MILLER-MOORE 24 HR FCST TRACK
AVG. 24 HR FCST ERROR—10 CASES—122.7 MI.
CHART 9
TSINGTAO
SHANGHAI
TOKYO
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
RANGOON
MANILA
SAIGON
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL


LUCY BEST TRACK
FNWF 24 HR FCST TRACK
FNWF 48 HR FCST TRACK
AVG. 24 HR FCST ERROR—9 CASES—208.2 MI
AVG. 48 HR FCST ERROR—7 CASES—476.4 MI
SHANGHAI
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
RANGOON
MANILA
SAIGON
ULITHI
YAP
KOROR
WOLEAI AT
CHART 10


LUCY BEST TRACK
JTWC 24HR FCST TRACK
JTWC 48HR FCST TRACK
AVG. 24 HR FCST ERROR- 20 CASES- 110.2 MI.
AVG. 48 HR FCST ERROR- 16 CASES- 220.7 MI.
CHART II
TSINGTAO
SHANGHAI
HONG KONG
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
RANGOON
SAIGON
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL


MEAN BEST TRACKS
TSINGTAO
SHANGHAI
HONG KONG
MANILA
SAIGON
RANGOON
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
112°30'E
142°30'E
H(−8)
I(−9)
K(−10)
CHART 12

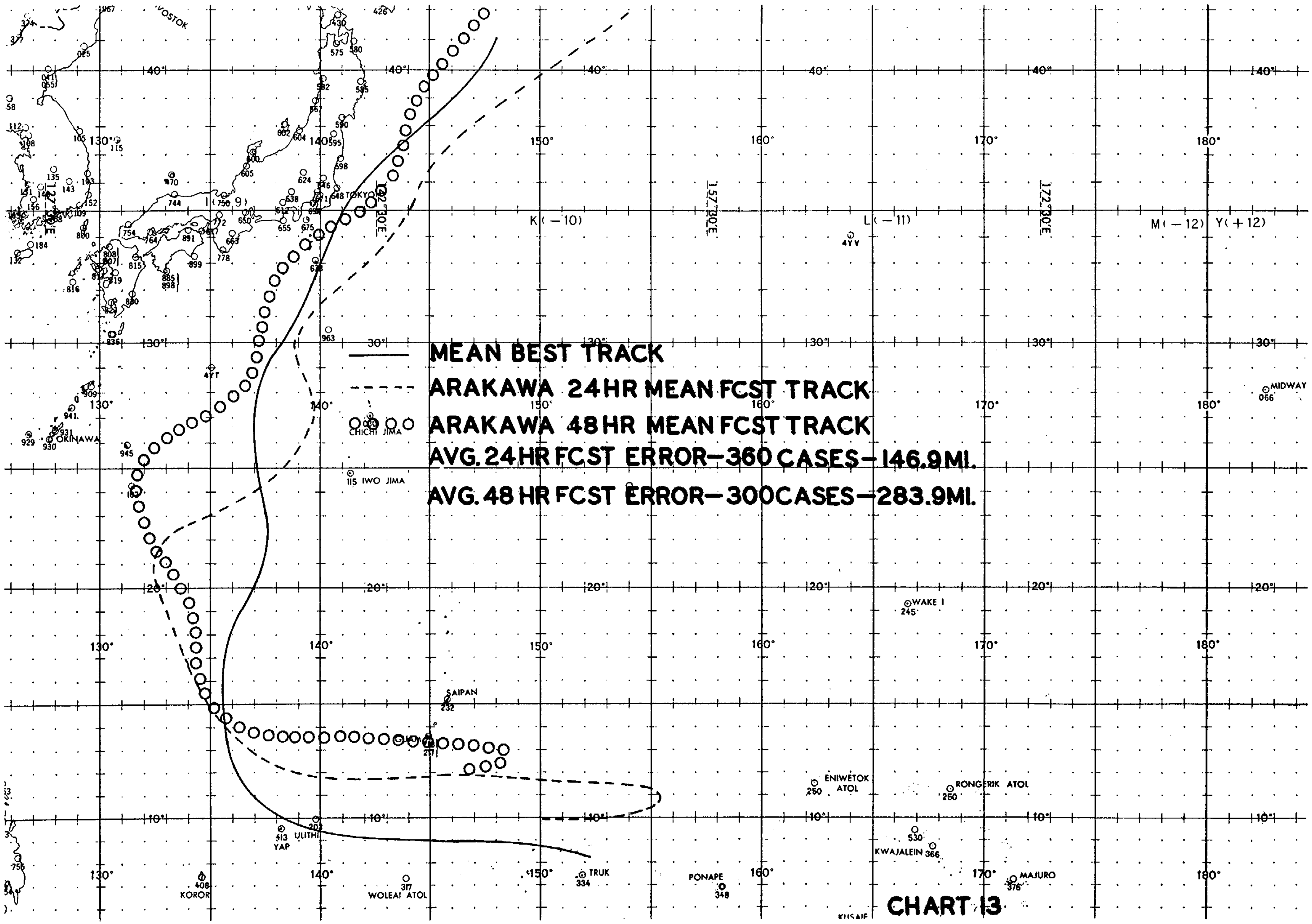
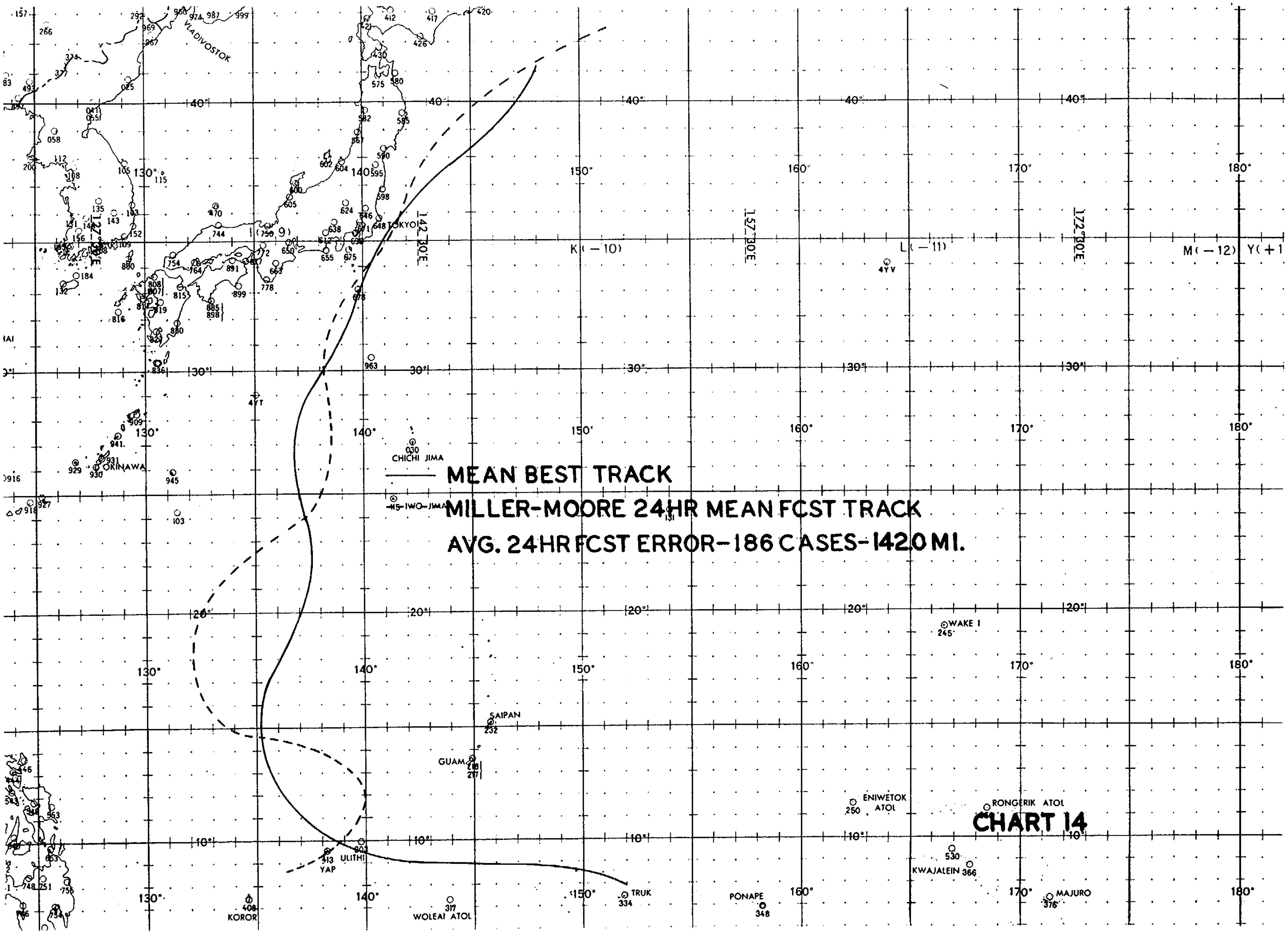

MEAN BEST TRACK
ARAKAWA 24HR MEAN FCST TRACK
ARAKAWA 48HR MEAN FCST TRACK
AVG. 24HR FCST ERROR—360 CASES—146.9MI.
AVG. 48HR FCST ERROR—300CASES—283.9MI.
TOKYO
CHICHI JIMA
IWO JIMA
OKINAWA
MIDWAY
WAKE I
SAIPAN
GUAM
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
TRUK
PONAPE
ULITHI
YAP
KOROR
WOLEAI ATOL
K(−10)
L(−11)
M(−12) Y(+12)

CHART 13


MEAN BEST TRACK
MILLER-MOORE 24HR MEAN FCST TRACK
AVG. 24HR FCST ERROR-186 CASES-142.0 MI.
CHART 14

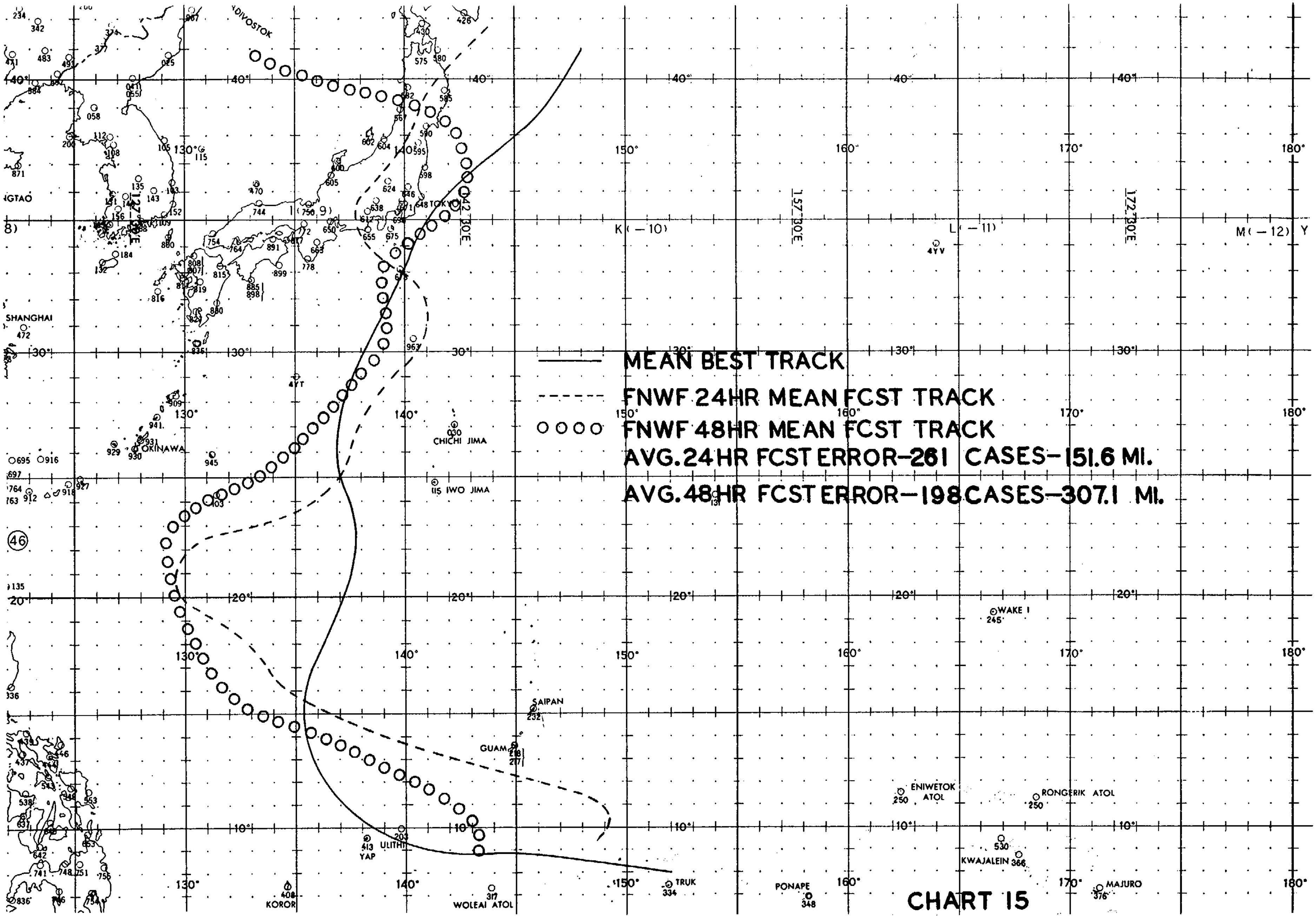
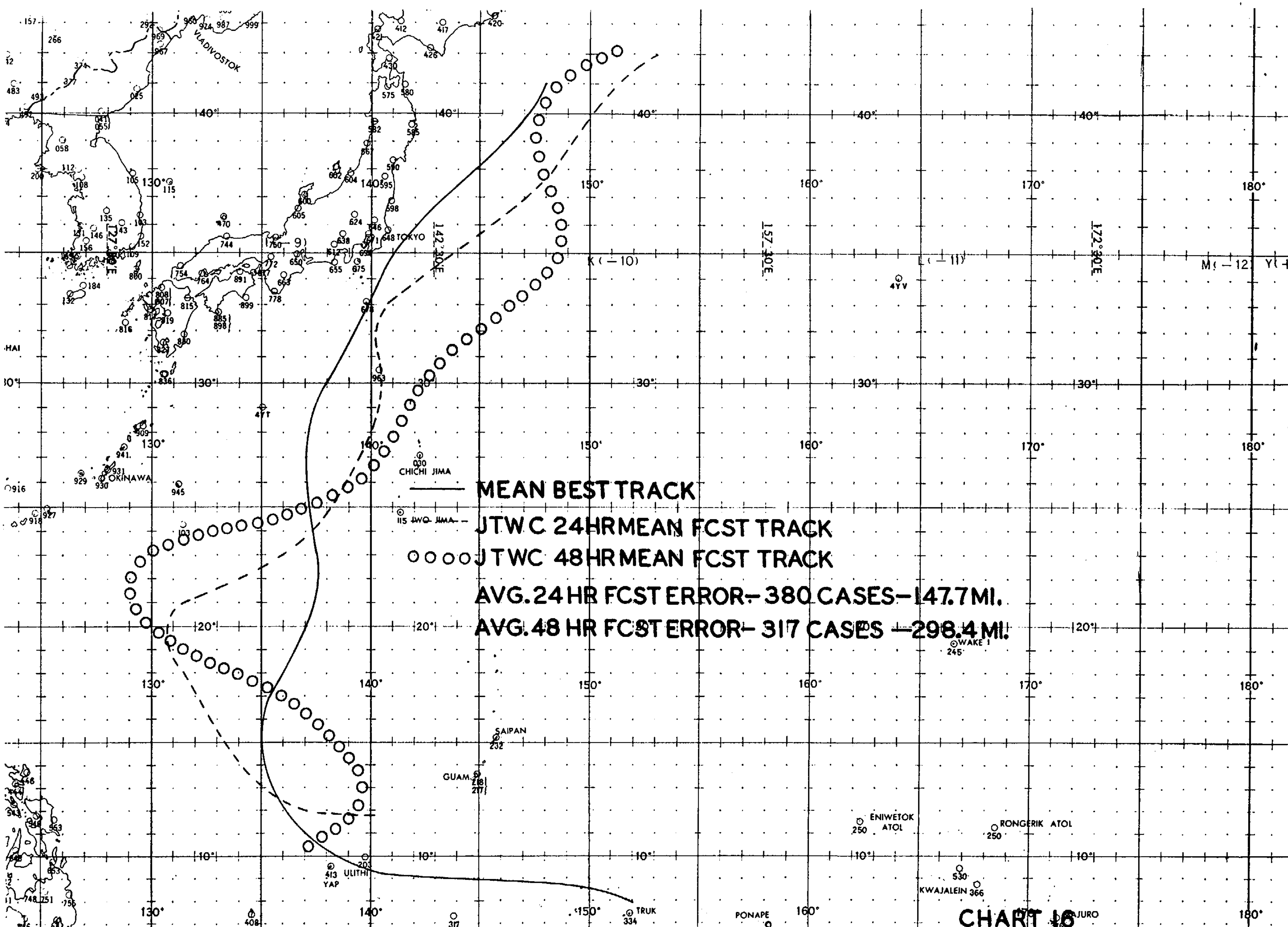
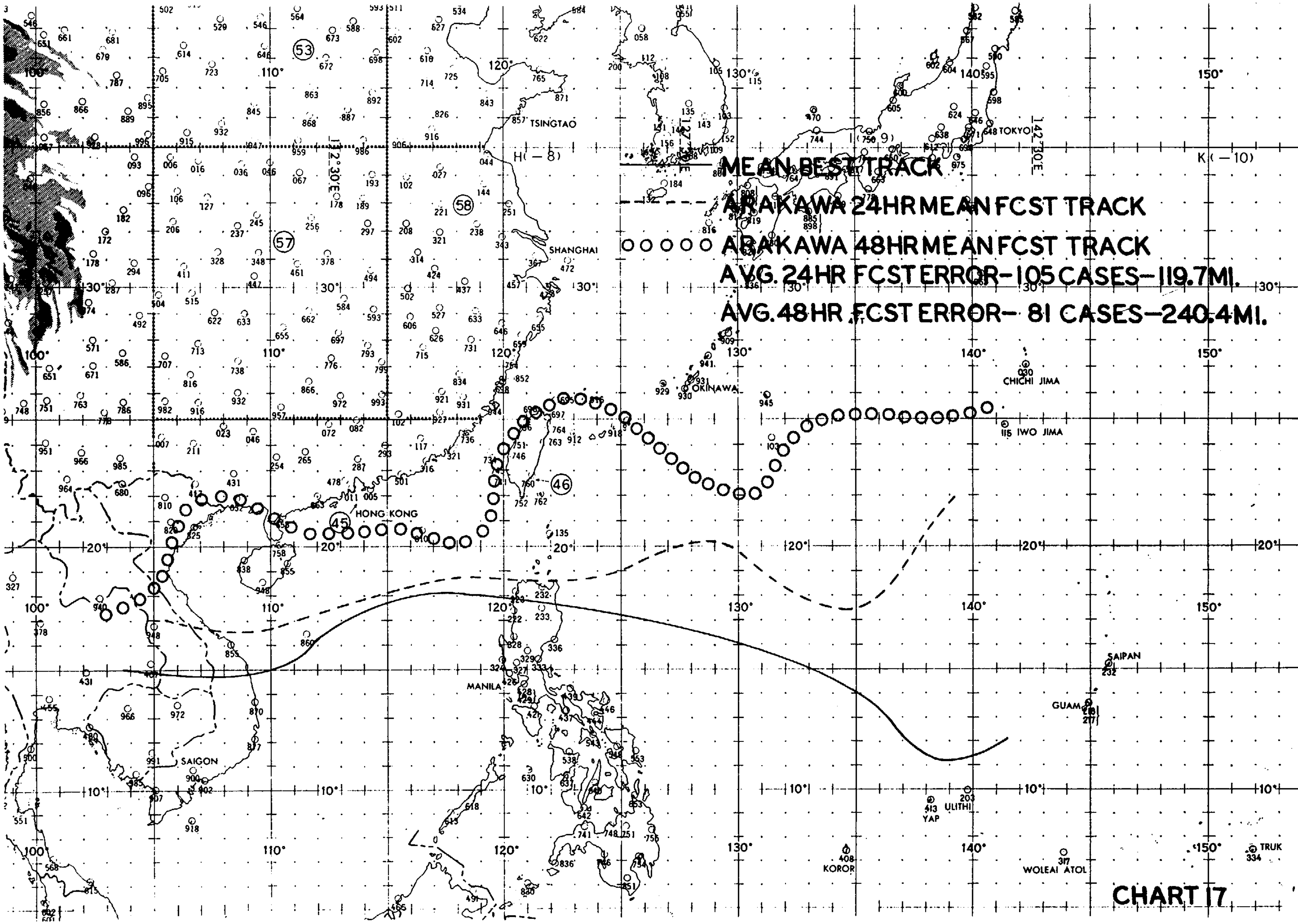
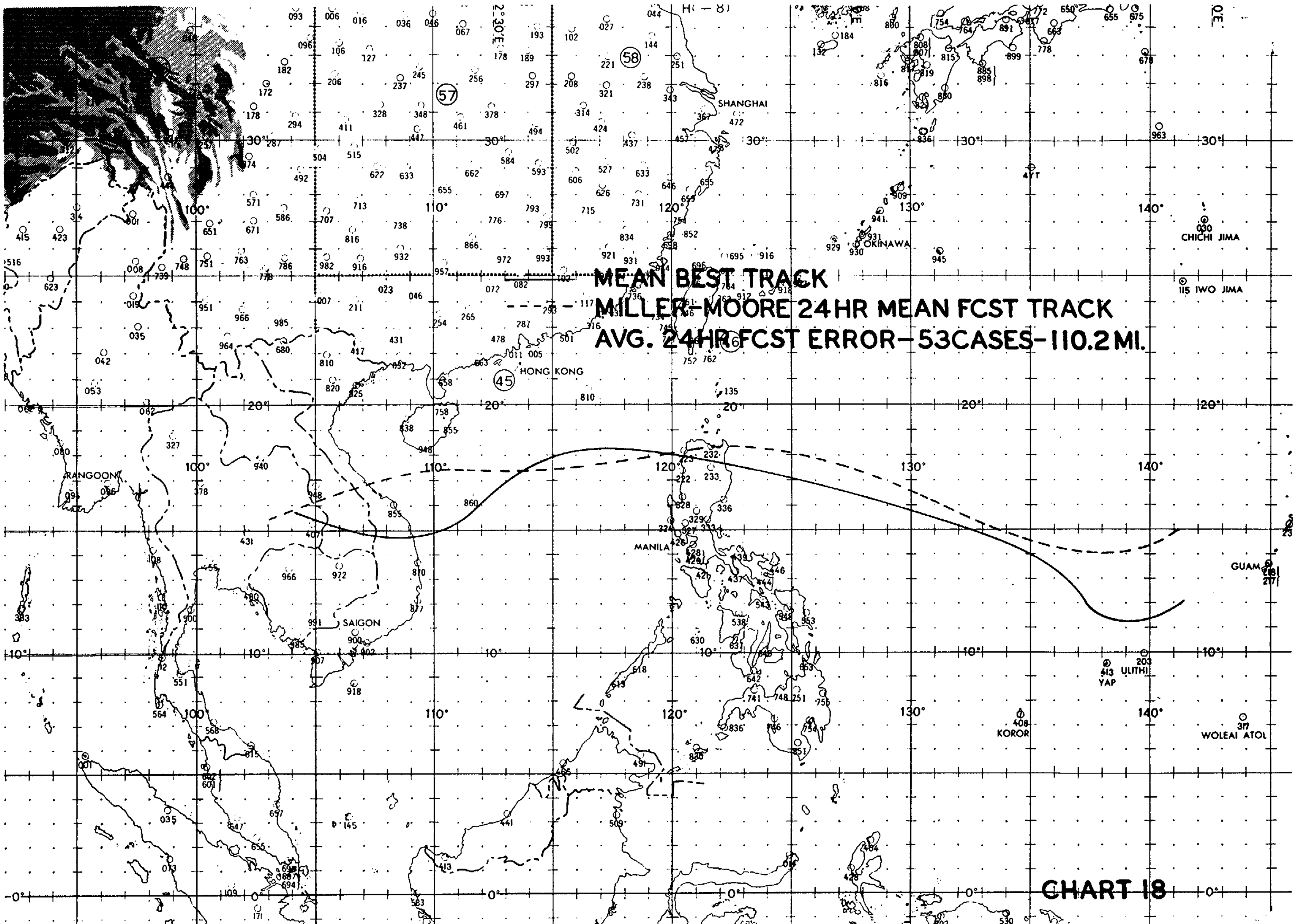
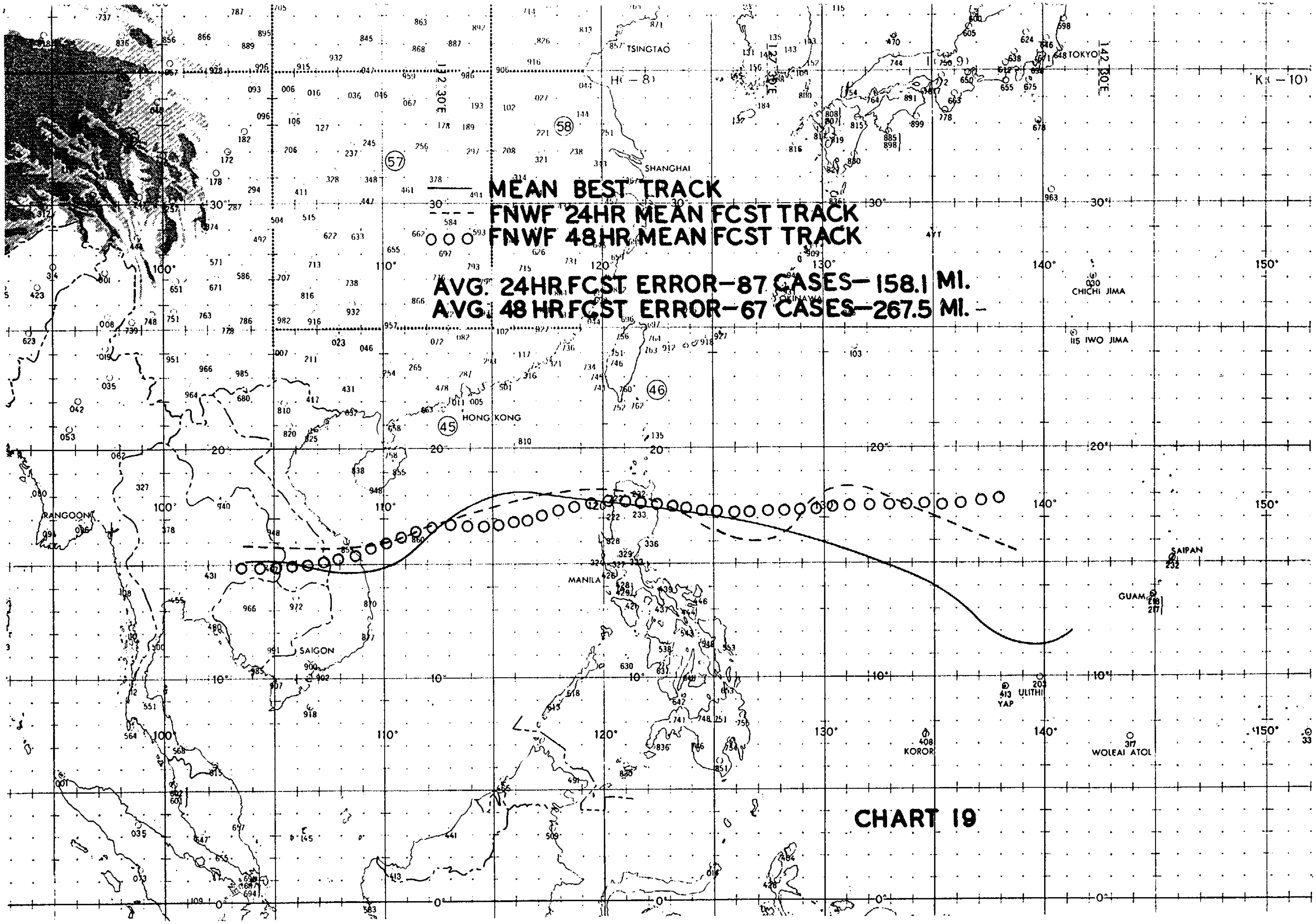

MEAN BEST TRACK
FNWF 24HR MEAN FCST TRACK
FNWF 48HR MEAN FCST TRACK
AVG. 24 HR FCST ERROR-261 CASES-151.6 MI.
AVG. 48 HR FCST ERROR-198 CASES-307.1 MI.
SHANGHAI
OKINAWA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I

CHART 15


MEAN BEST TRACK
JTWC 24HR MEAN FCST TRACK
JTWC 48HR MEAN FCST TRACK
AVG. 24 HR FCST ERROR - 380 CASES - 147.7 MI.
AVG. 48 HR FCST ERROR - 317 CASES - 298.4 MI.
VLADIVOSTOK
TOKYO
CHICHI JIMA
IWO JIMA
OKINAWA
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
WAKE I
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
CHART 16


MEAN BEST TRACK
ARAKAWA 24HR MEAN FCST TRACK
ARAKAWA 48HR MEAN FCST TRACK
AVG. 24HR FCST ERROR-105 CASES-119.7MI.
AVG. 48HR FCST ERROR- 81 CASES-240.4MI.
TSINGTAO
SHANGHAI
HONG KONG
TOKYO
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
SAIGON
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
CHART 17


MEAN BEST TRACK
MILLER-MOORE 24HR MEAN FCST TRACK
AVG. 24HR FCST ERROR–53CASES–110.2MI.
SHANGHAI
HONG KONG
MANILA
SAIGON
RANGOON
OKINAWA
CHICHI JIMA
IWO JIMA
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
CHART 18


MEAN BEST TRACK
FNWF 24HR MEAN FCST TRACK
FNWF 48HR MEAN FCST TRACK
AVG. 24HR FCST ERROR—87 CASES—158.1 MI.
AVG. 48 HR FCST ERROR—67 CASES—267.5 MI.
CHART 19
TSINGTAO
SHANGHAI
TOKYO
OKINAWA
HONG KONG
MANILA
SAIGON
RANGOON
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL

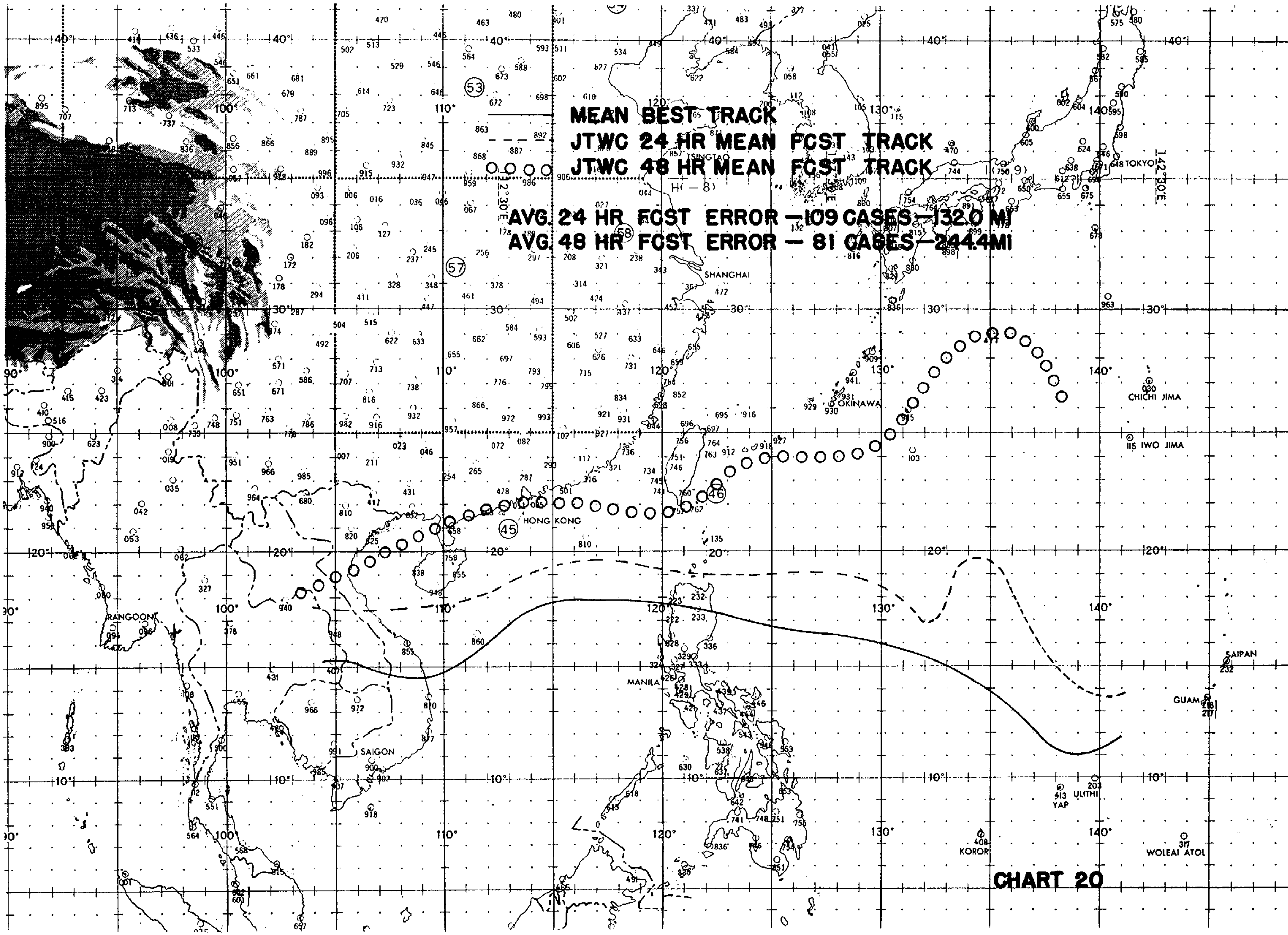

MEAN BEST TRACK
JTWC 24 HR MEAN FCST TRACK
JTWC 48 HR MEAN FCST TRACK
AVG. 24 HR FCST ERROR — 109 CASES — 132.0 MI
AVG. 48 HR FCST ERROR — 81 CASES — 244.4 MI
SHANGHAI
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
TOKYO
RANGOON
SAIGON
MANILA
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL

CHART 20

24-HOUR TYPHOON FORECAST ERRORS OF 1962

	ARAKAWA		FNWF		MILLER-MOORE	
TYPHOON	NO. OF CASES	MEAN ERROR	NO. OF CASES	MEAN ERROR	NO. OF CASES	MEAN ERROR
GEORGIA	20	208	--	---	13	165
HOPE	21	128	--	---	11	158
IRIS	6	225	--	---	2	87
JOAN	13	155	5	184	7	114
KATE	16	201	8	286	7	154
LOUISE	28	168	12	148	13	149
NORA	20	183	22	172	10	234
OPEL	14	114	15	228	7	103
PATSY	13	119	11	294	7	88
RUTH	32	134	24	139	16	108
SARAH	27	132	17	190	13	139
THELMA	22	124	20	118	11	79
VERA	9	128	8	97	4	252
WANDA	15	92	16	134	7	118
AMY	33	136	25	127	17	130
CARLA	7	173	7	79	4	77
DINAH	18	172	18	130	9	93
EMMA	36	143	34	163	18	148
FREDA	21	145	21	121	11	91
GILDA	31	93	31	109	15	139
IVY	--	---	--	---	--	---
JEAN	18	102	20	103	9	147
KAREN	25	154	34	190	18	157
LUCY	20	95	--	---	10	123

AVERAGE ERROR-ARAKAWA (465 CASES).................. 141
AVERAGE ERROR-FNWF (348 CASES)..................... 153
AVERAGE ERROR-MILLER-MOORE (239 CASES)............. 135

48-HOUR TYPHOON FORECAST ERRORS OF 1962

TYPHOON	ARAKAWA NO. OF CASES	ARAKAWA MEAN ERROR	FNWF NO. OF CASES	FNWF MEAN ERROR
GEORGIA	17	365	--	---
HOPE	18	270	--	---
IRIS	4	429	--	---
JOAN	9	375	1	150
KATE	12	360	--	---
LOUISE	24	264	--	---
NORA	16	238	17	322
OPEL	10	216	11	350
PATSY	9	222	7	560
RUTH	27	337	19	305
SARAH	23	237	15	380
THELMA	18	241	15	280
VERA	5	280	4	170
WANDA	11	261	12	175
AMY	29	287	21	164
CARLA	3	339	3	130
DINAH	14	434	16	273
EMMA	32	271	31	361
FREDA	17	252	17	254
GILDA	27	220	27	277
IVY	--	---	--	---
JEAN	18	188	18	183
KAREN	22	309	31	399
LUCY	16	123	--	---

AVERAGE ERROR-ARAKAWA (381 CASES).................. 274
AVERAGE ERROR-FNWF (265 CASES)..................... 297

TYPHOON ACCELERATION AFTER RECURVATURE

by

LTJG E. A. Erdei, USN

One of the primary problems which confronted JTWC during 1962 was forecasting the speed of movement of typhoons. A method is presented here for determining accelerations of typhoons after recurving into the westerlies.

Data was initially selected from the 1959 and 1960 seasons, which produced 17 typhoons that recurved. Numerous methods were tried using 47 cases from the 17 typhoons. Twelve and 24-hour cyclone speed differences were compared to the maximum winds at the 700, 500, 300 and 200mb levels. The best correlation was obtained by using the cyclone speed difference over a 24-hour period and comparing this value with the maximum wind speed difference for the past 12 hours at the "capping level." This comparison produced the curve shown herein.

A hypothetical example follows:

1 DTG	2 MAX WND SPD	3 12HR WND SPD DIFF (2C-2B)	4 SPD FROM ACCEL CURVE (Abscissa Value)		5 CYC SPD AT TIME Col #1		6 24HR SPD DIFF (5C-5A)		7 FCST SPD AT 1C+24 4C+5C+6C
A.2000Z	X	X	X		10		X		X
B.2012Z	20	X	X		X		X		X
C.2100Z	25	5	3	+	20	+	10	=	33

1. Time of upper level chart being used to obtain maximum winds.

2. Maximum wind speeds are taken from the "capping level," which is defined as the lowest standard level the cyclone is not a closed system. This level may not be the same from one 12-hour period to the next, and in no case should a standard level above 200mb be used, whether the system appears to be closed at 200mb or not.

Locate the surface position of the tropical cyclone at the selected "capping level" and draw a circle from this point with a 300 mi radius. Should the cyclone be in the ridge line, estimate the maximum wind present in the NW quadrant of the circle. If it has recurved, use the W quadrant for the maximum wind value.

3. Maximum wind speed difference during the past 12 hours (Note: the maximum speeds may have come from different levels).

4. Enter the figure obtained from 3C on the Acceleration curve abscissa and move up to the curve and read the ordinate value.

5. Cyclone speed at the time shown in Column 1.

6. Cyclone speed difference during the past 24 hours.

7. Add the figures from 4C, 5C and 6C. This should be the speed of the cyclone 24 hours after the time 1C.

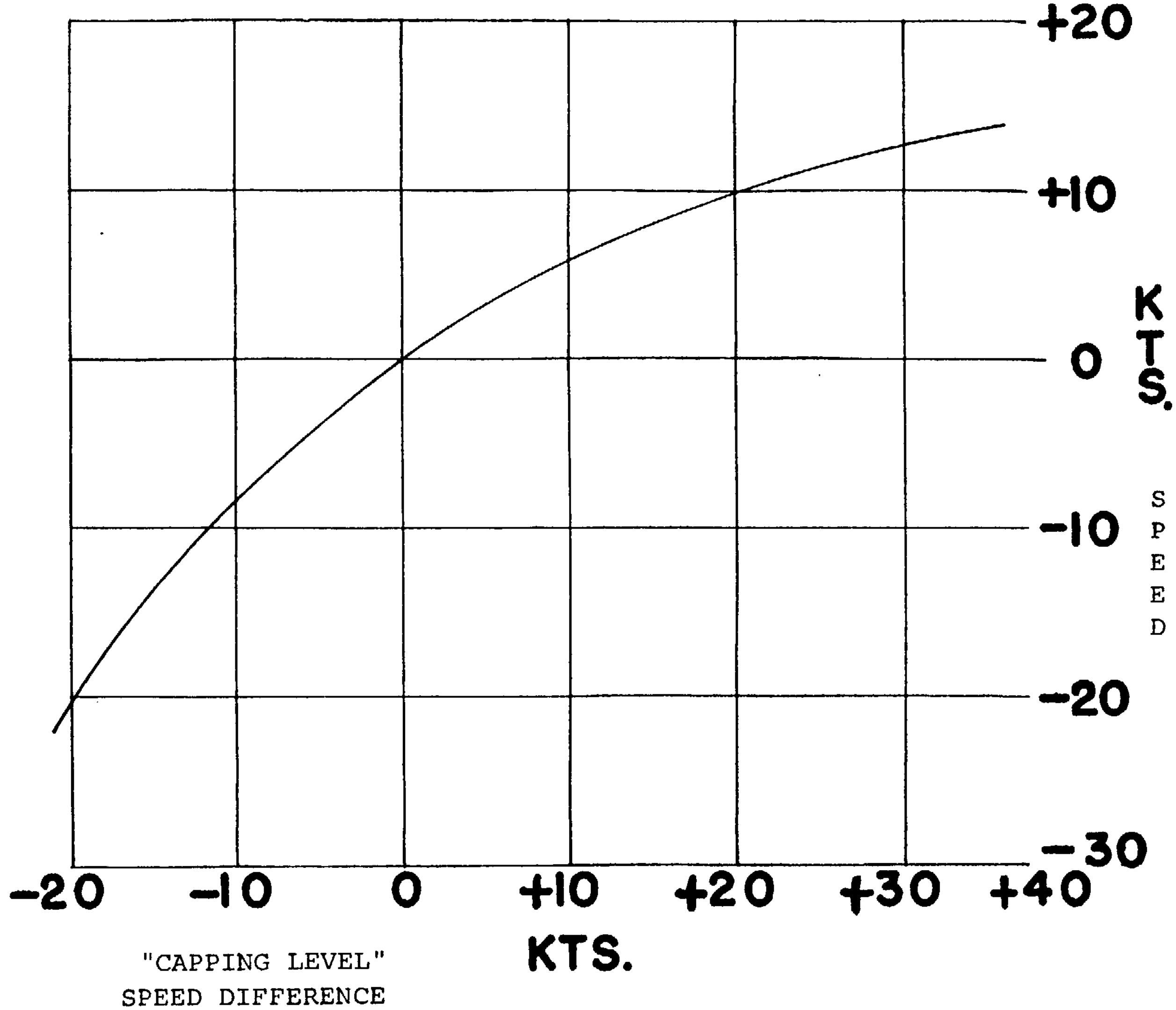
This technique was first evaluated in 1961. There were 31 cases with an average error of 7 kts. Twenty of the cases averaged 8 kts low while 11 of the cases averaged 6 kts high as compared to the best track speed. These cases were incorporated into the previous two years of data.

In 1962 there were 41 cases with an average error of 7 kts. Twenty-two of the cases averaged 8 kts low while 14 of the cases averaged 8 kts high as compared to the best track speed. It has been observed that the forecaster is usually on the low side of the verified speed when forecasting the speed of movement of a cyclone after recurvature. As noted above, this system produces a higher, more accurate, forecast speed; therefore, as a forecast aid, it will assist the forecaster in terms of higher speeds in 1963.

ACCELERATION AFTER RECURVATURE

24 HOUR

FORECAST



TYPHOON EYE TERMINOLOGY

by

LT Harry D. Hamilton, USN

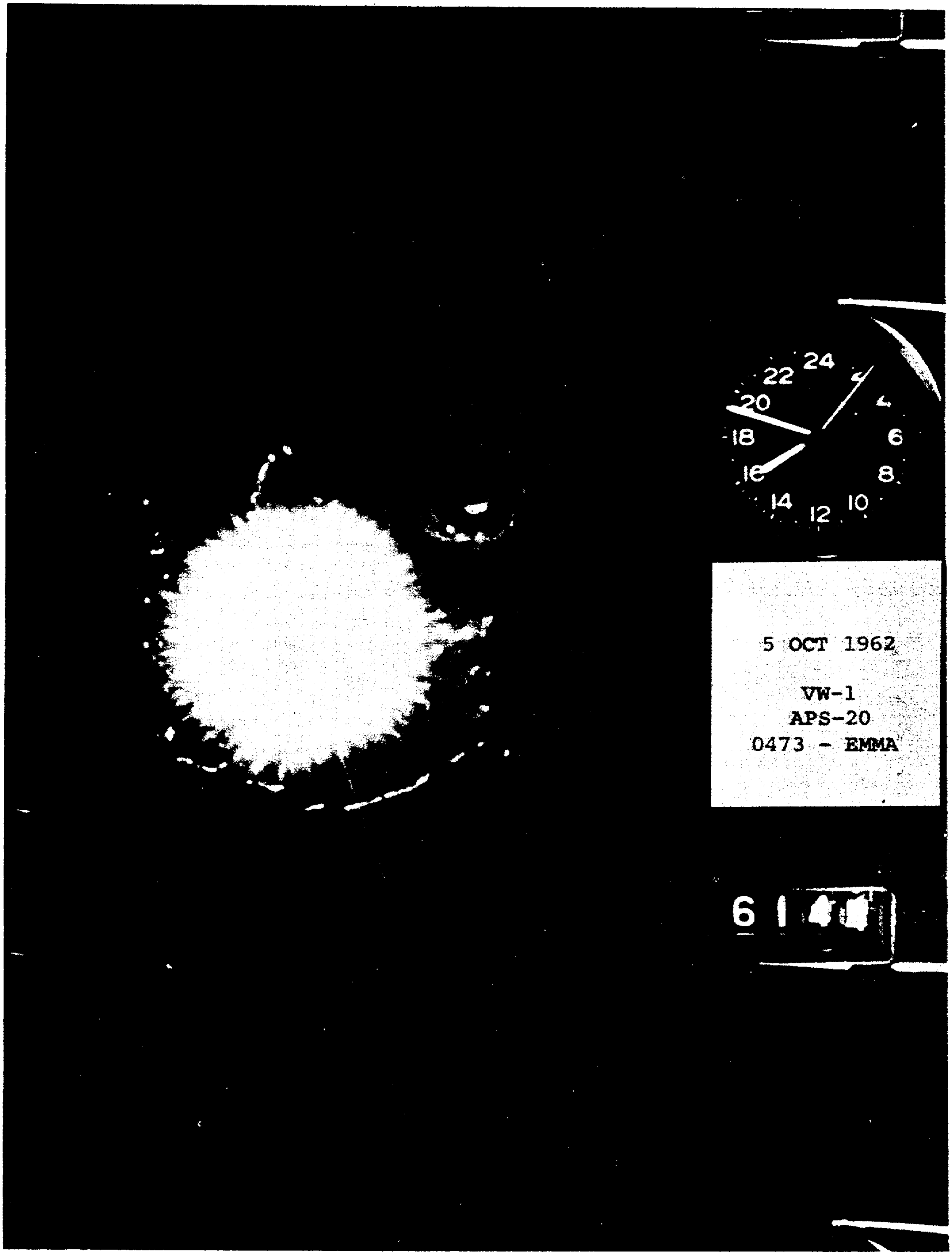
In the field of meteorology, as in other scientific fields of endeavor, the need for standardization of terminology is ever present. The time for standardization is before a double standard is in practice. This alleviates the necessity of explaining the terminology to insure that the correct "standard" is being conveyed to the receiver (12). This latter need is mandatory in terse aircraft reconnaissance reports. The requirement for standardized meanings for "concentric eye" and "double eye" is imperative in that a particular typhoon can have a concentric eye or double eye in their true sense, thereby eliminating the possibility of the dual use of the latter term. During 1962 in the Western Pacific, it was not unusual for typhoons to have concentric eyes when they had wind speeds in excess of 120 kts. More rarely, they had double eyes, usually when they were less intense. The typhoons with a concentric eye were THELMA, AMY and EMMA, with a double eye were DINAH and GILDA, and those that were both concentric eyed and double eyed at different times were RUTH and KAREN. All of the above typhoons were also single eyed at various times during their typhoon cycle.

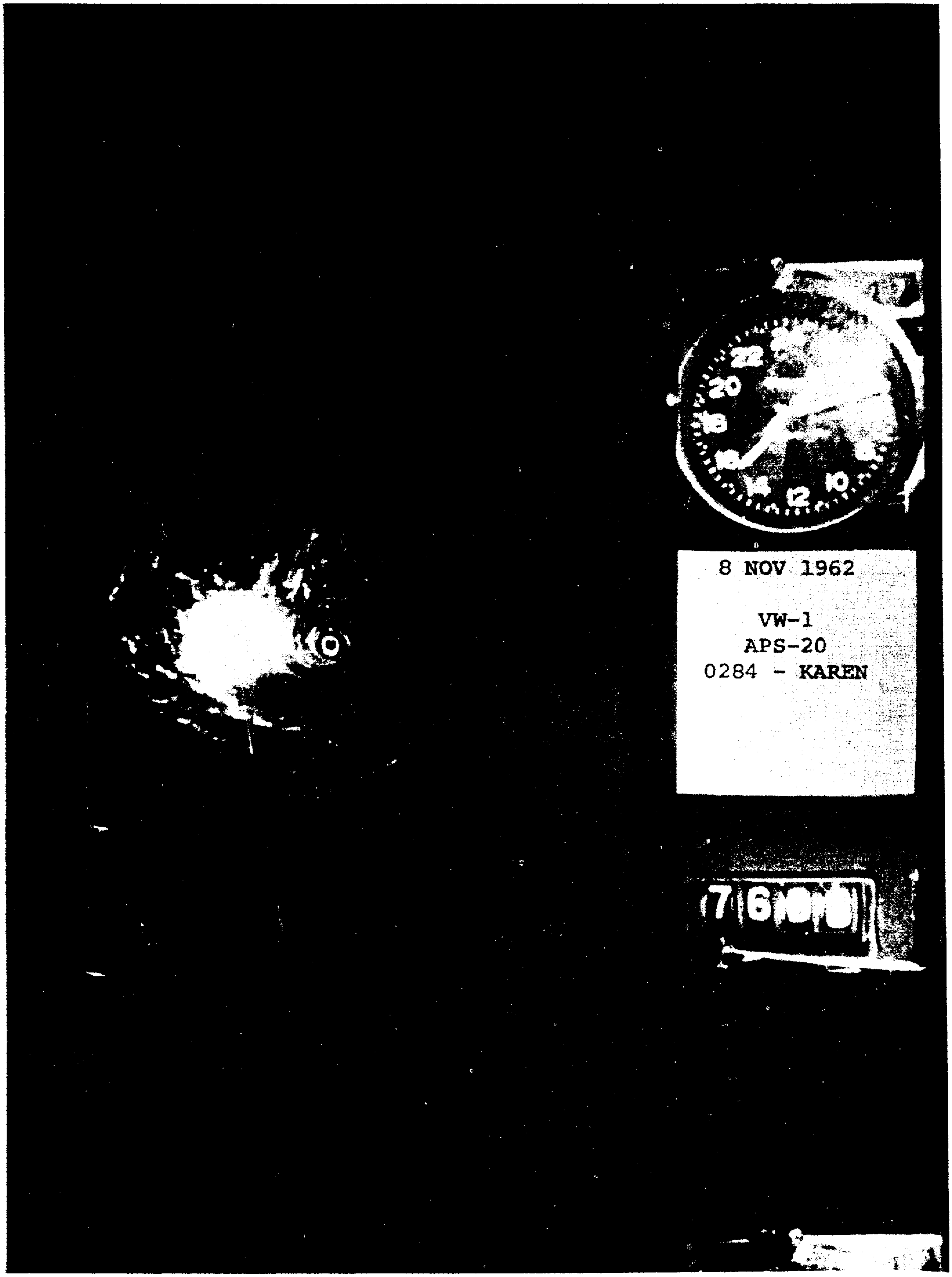
When describing the eye of a typhoon, the term "concentric eye" should be used only to describe a typhoon which has one eye circumscribed by another eye. The term "double eye" should be used only to describe a typhoon which has two separate eyes, neither of which is contained within the other. Both the "concentric eye" and "double eye" typhoons have their singular or dual centers within the lowest pressure area; whereas, a false eye can exist outside the wall clouds of the above eyes. Thus, a typhoon with one real eye and one false eye should not be described as a typhoon with a "double eye." The best examples this year of false eyes causing inexperienced ground radar observers to make erroneous reports were Typhoons NORA and EMMA. In both of these cases, the false eye life span was less than twelve hours.

The "double eye" typhoon puts an additional burden on both the reconnaissance squadrons and on the typhoon forecasters. To insure consistent meteorological intensification parameters and enable a more accurate movement to be determined, one eye must be selected for fixes. This particular eye should be the primary eye, if such exists, or an arbitrarily selected eye because of a discernible feature. The reconnaissance aircraft must then insure that its primary report is on the primary eye and that any information on the secondary eye is definitely isolated. Forecasting may be complicated by the cyclonic rotation of the eyes about an apparent mass center. This may be described as a meso-scale Fujiwhara effect.

Pictorial examples of "concentric eye" typhoons are EMMA and KAREN. "Double eye" typhoon negatives were not available for printing and confirmation was extracted from reconnaissance logs.

It is strongly recommended that the terminology presented in this paper be adopted as the standard by all tropical meteorologists.


24
22
20
18
16
14
12
10
8
6
5 OCT 1962
VW-1
APS-20
0473 - EMMA


8 NOV 1962
VW-1
APS-20
0284 - KAREN

INVESTIGATION OF TYPHOON SURFACE GUSTS

by
Mr. George Taniguchi
1st Weather Wing Staff
Fuchu Air Station, Japan

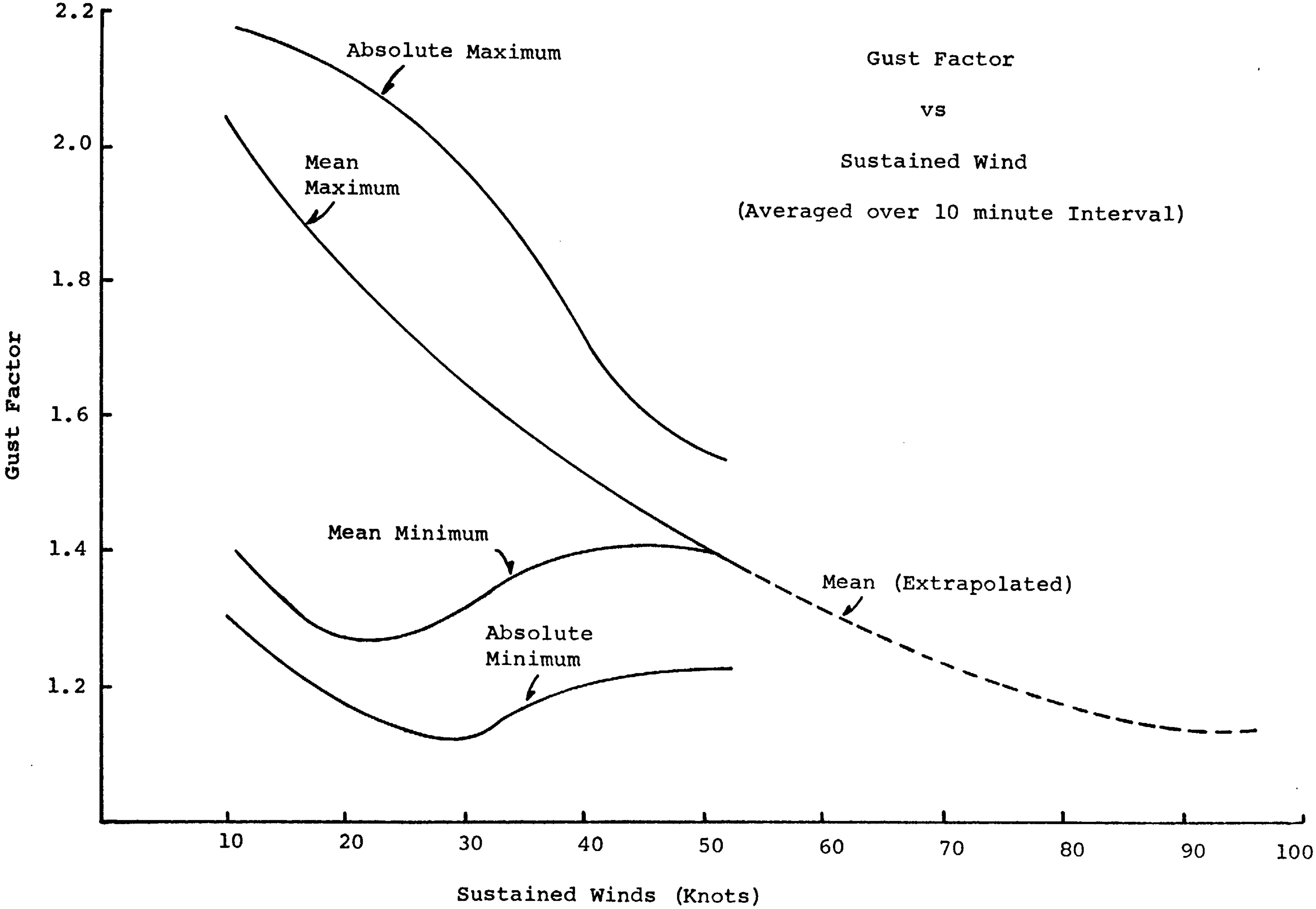
An investigation was made to determine the existence of suitable parameters which may be correlated with surface gusts in a typhoon. Data used for this investigation was extracted from the hourly sequence reports given in the typhoon reports issued by the Japan Meteorological Agency's Tokyo International Airport Aviation Weather Service from 1955 to 1962. The sequence reports were from the various stations within Japan and Okinawa which were affected by the typhoons.

Gust factors were computed and plotted against sustained wind (defined as the mean wind over an interval of 10 minutes), and also against sea level pressure reported by the stations. No apparent correlations were seen from either of the set of plots made, except for a vague trend of higher gusts with lower sustained winds. The curves for absolute maximum and minimum and mean maximum and minimum values are given in the following chart. The curves are based on observed data of ten typhoons (1955-1962) which affected Okinawa and Japan. As can be seen from the chart, there is a wide range of variation in the gust factors from 10 to 30 kts of sustained winds. From 30 kts, the upper and lower limits of the mean decrease and merge at about 50 kts. Beyond 50 kts, the gust factor seems to decrease exponentially when extrapolated. The report on Typhoon VERA (11) by JMA states that difficulty was encountered in attempting to correlate maximum gusts with maximum mean winds in a typhoon since the occurrence of maximum gusts often does not coincide with maximum mean winds. Furthermore, the local terrain features seem to have a much greater influence on the magnitude of gusts than the mean winds. This report concludes that the gust factors range between 1.2 and 1.5 for all land stations (mean of 1.4) and between 1.2 and 1.8 for just the coastal stations (mean of 1.3 sic) in the case of Typhoon VERA (September 1959).

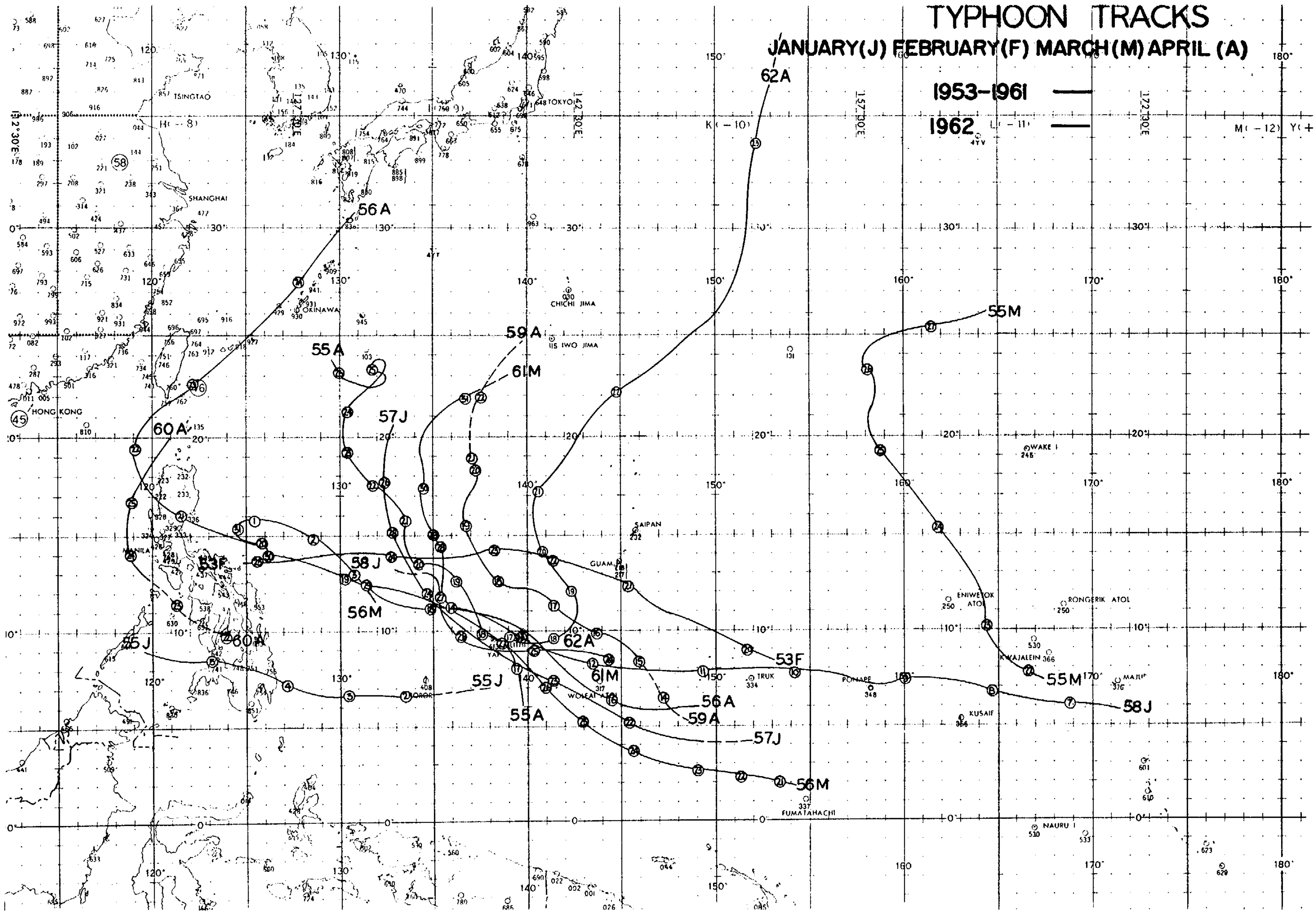
JMA's first order observatories are equipped with the Dines pressure anemometer in addition to the Robinson type 3 cup anemometer. The Dines anemometer is used specifically for recording gusty winds. The diameter of the pressure tube used by JMA is approximately 1.0 cm. The mean gust factor of 1.40 for all land stations, as reported by JMA, is substantiated by G. J. Bell's (2) mean gust factor of 1.47 for typhoons affecting Hong Kong. Bell based his investigation of gust factors (maximum gust/mean hourly wind speed) on data spanning a period of 7 years. The observations of gusts were made using the Dines anemometer with a pressure tube having a diameter of 1.27 cm. The fact that the mean gust factor reported by JMA is slightly less than that reported by Bell may be attributed to the smaller tube diameter used by JMA. This conclusion is based on Bell's assumption that a smaller tube diameter has a dampening effect. Bell obtained a mean of 1.69 using a 2.54 cm tube over a 7 year period versus 1.47 with a 1.27 cm tube over the same period. Based on Bell's estimate, the difference in the mean gust factor between the "mean over an hour" (H - 30 minutes to H + 30 minutes) as used by Bell, and the "mean over a 10 minute period" as used by JMA, results in a higher mean wind for the latter by 2 to 6 percent of the former. Thus, this also may be a contributing factor to JMA's lower mean gust factor.

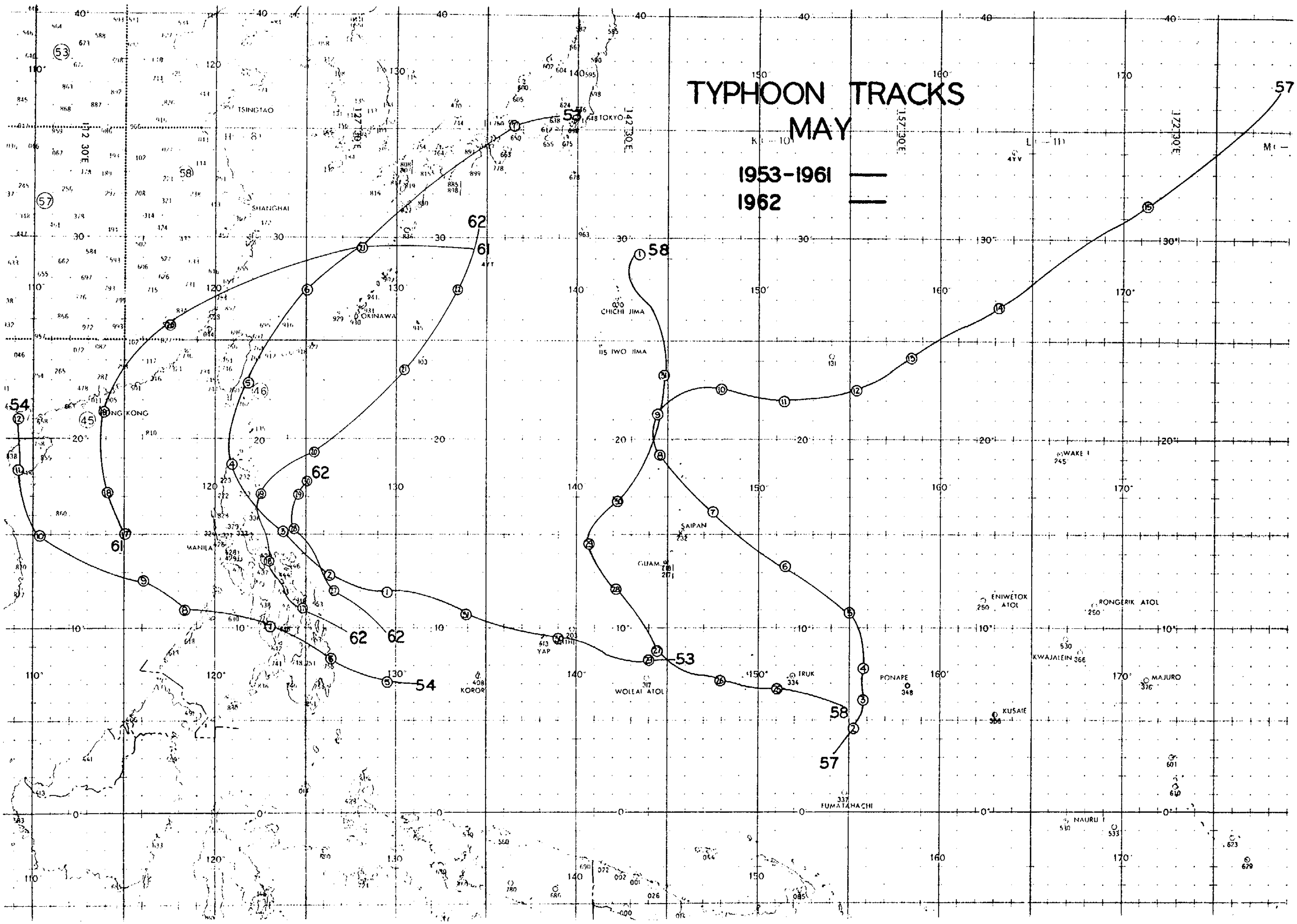
The most probable gust factors associated with hurricane winds as given by Mook (10) are 1.65 at a mean wind speed (over 5 minutes) of 30 to 40 kts, 1.5 at 50 kts and 1.4 at 60 kts, with maximum gust factors of 2.2 at 30 kts decreasing to 1.45 at 60 kts. No mention is given as to how these figures were derived.

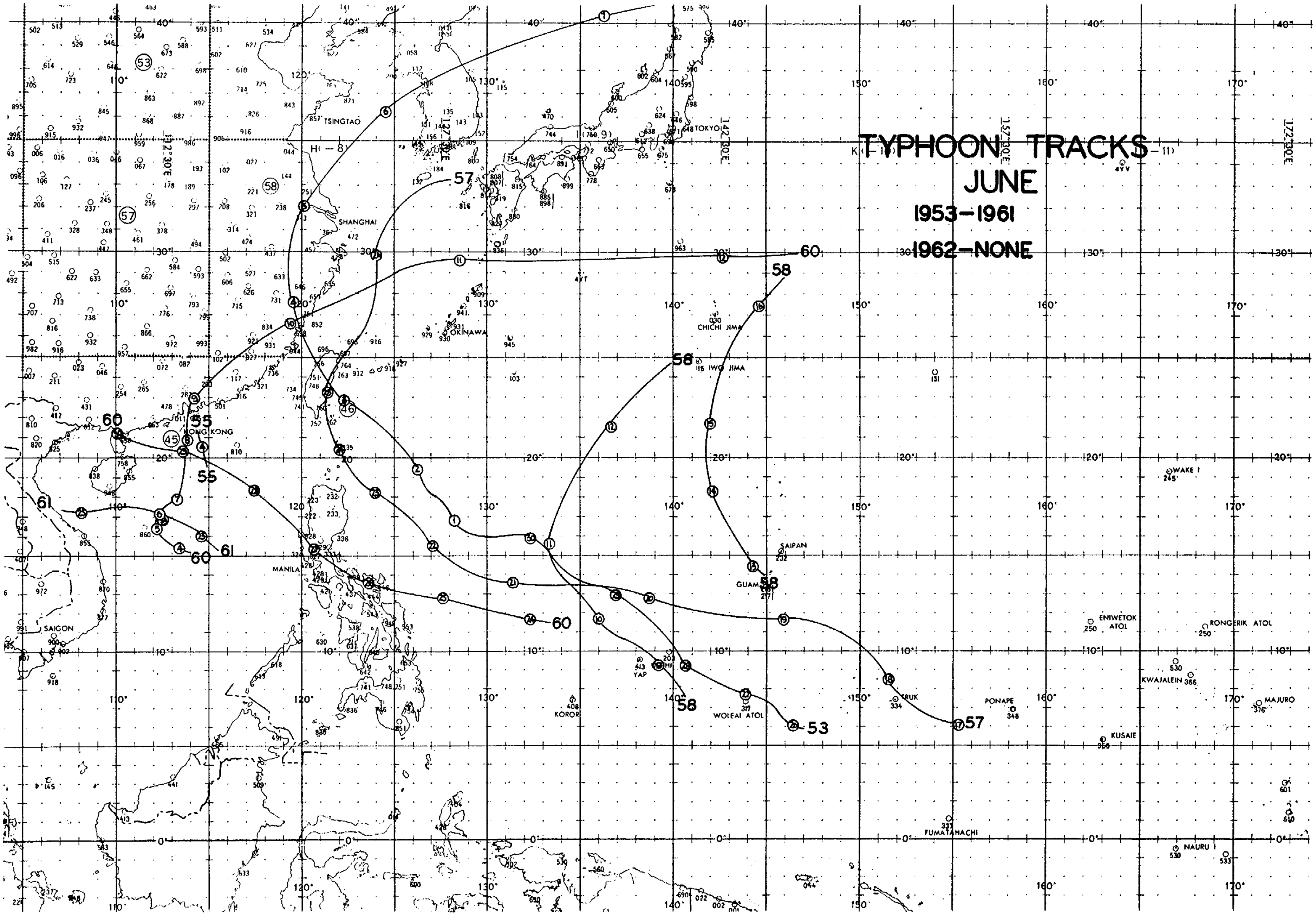
Difficulty is encountered in establishing a feasible method of forecasting typhoon gusts which may be applicable to any one or more stations affected by typhoon winds. This is due to the fact that local terrain features have a considerable influence on the magnitude of gusty winds. Exposure conditions of anemometers may differ considerably among observation sites, such as the height of the anemometer and the nature of the surrounding area. Different types of anemometers may give different values. Furthermore, a certain amount of difference in mean values exists with different definitions of the mean wind. For instance, Bell uses the mean over a one hour period in his report, JMA uses an interval of 10 minutes, while the USAF Air Weather Service uses a one minute interval. Coupled with these differences are factors involving typhoon intensities and the position of typhoon centers with respect to the observation sites. Thus, a statistical study using past wind data from all of the stations under different agencies during periods of typhoons will, at best, give only a generalized mean value.


Gust Factor
vs
Sustained Wind
(Averaged over 10 minute Interval)
Absolute Maximum
Mean
Maximum
Mean Minimum
Absolute
Minimum
Mean (Extrapolated)
Gust Factor
2.2
2.0
1.8
1.6
1.4
1.2
10
20
30
40
50
60
70
80
90
100
Sustained Winds (Knots)

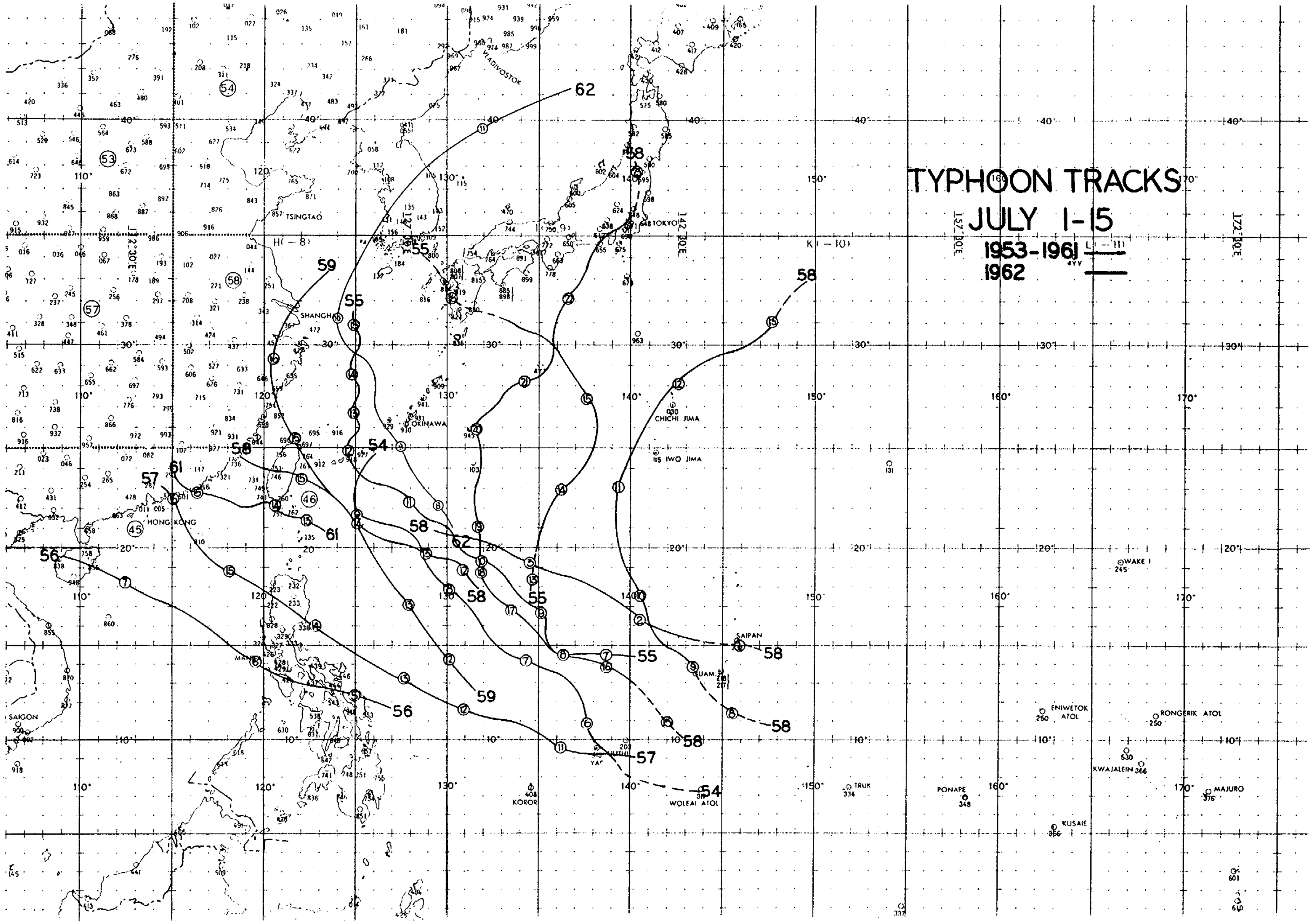
TYPHOON TRACKS, 1953-1962

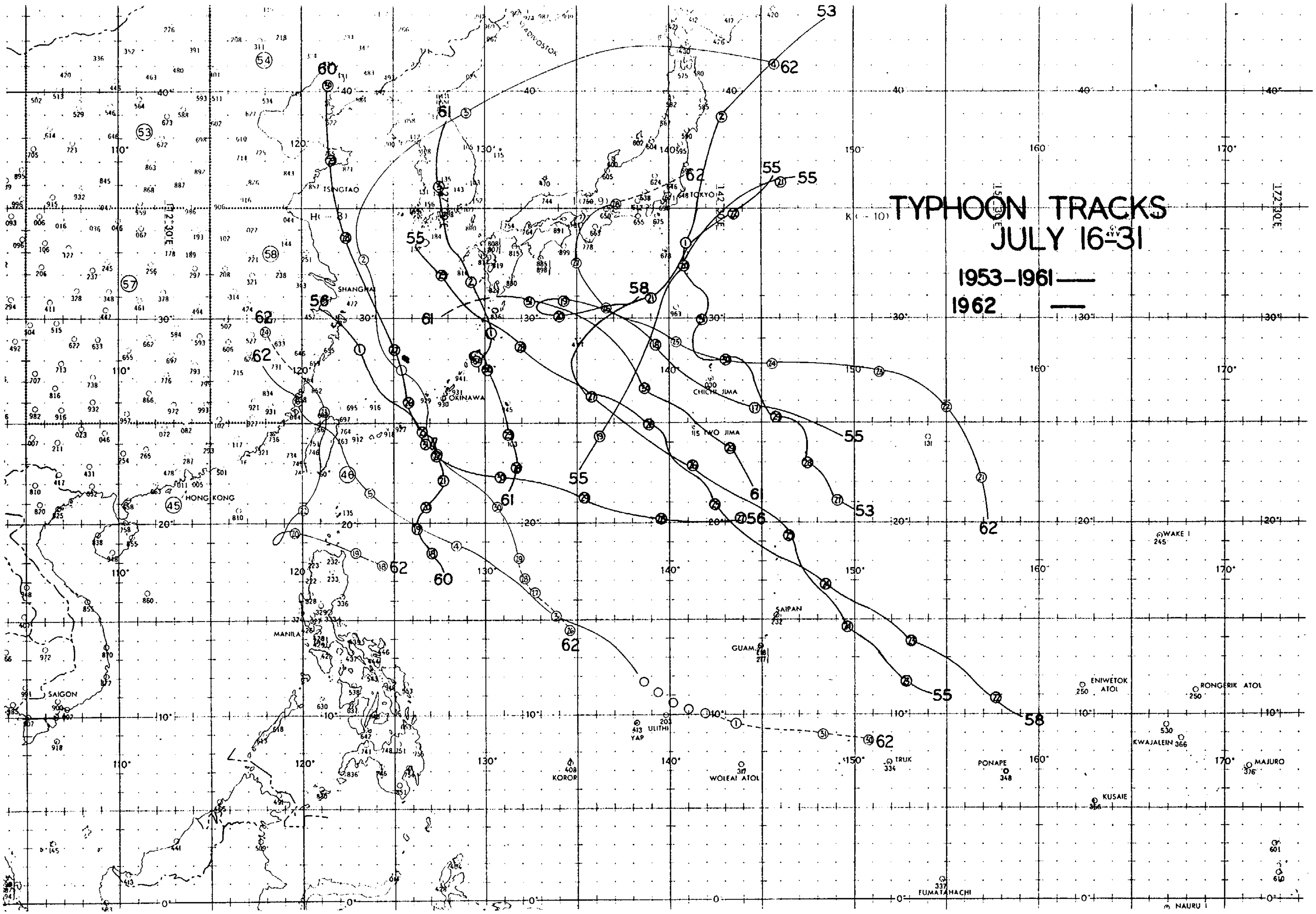

TYPHOON TRACKS
JANUARY(J) FEBRUARY(F) MARCH(M) APRIL (A)
1953-1961
1962
62A
56A
55A
59A
61M
57J
60A
53F
58J
56M
55J
62A
61M
56A
59A
57J
55A
56M
53F
55M
58J
TSINGTAO
TOKYO
SHANGHAI
OKINAWA
CHICHI JIMA
IWO JIMA
HONG KONG
MANILA
SAIPAN
GUAM
YAP
WOLEAI ATOLL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOLL
RONGERIK ATOLL
KWAJALEIN
MAJURO
WAKE I
NAURU I
FUMATAHACHI

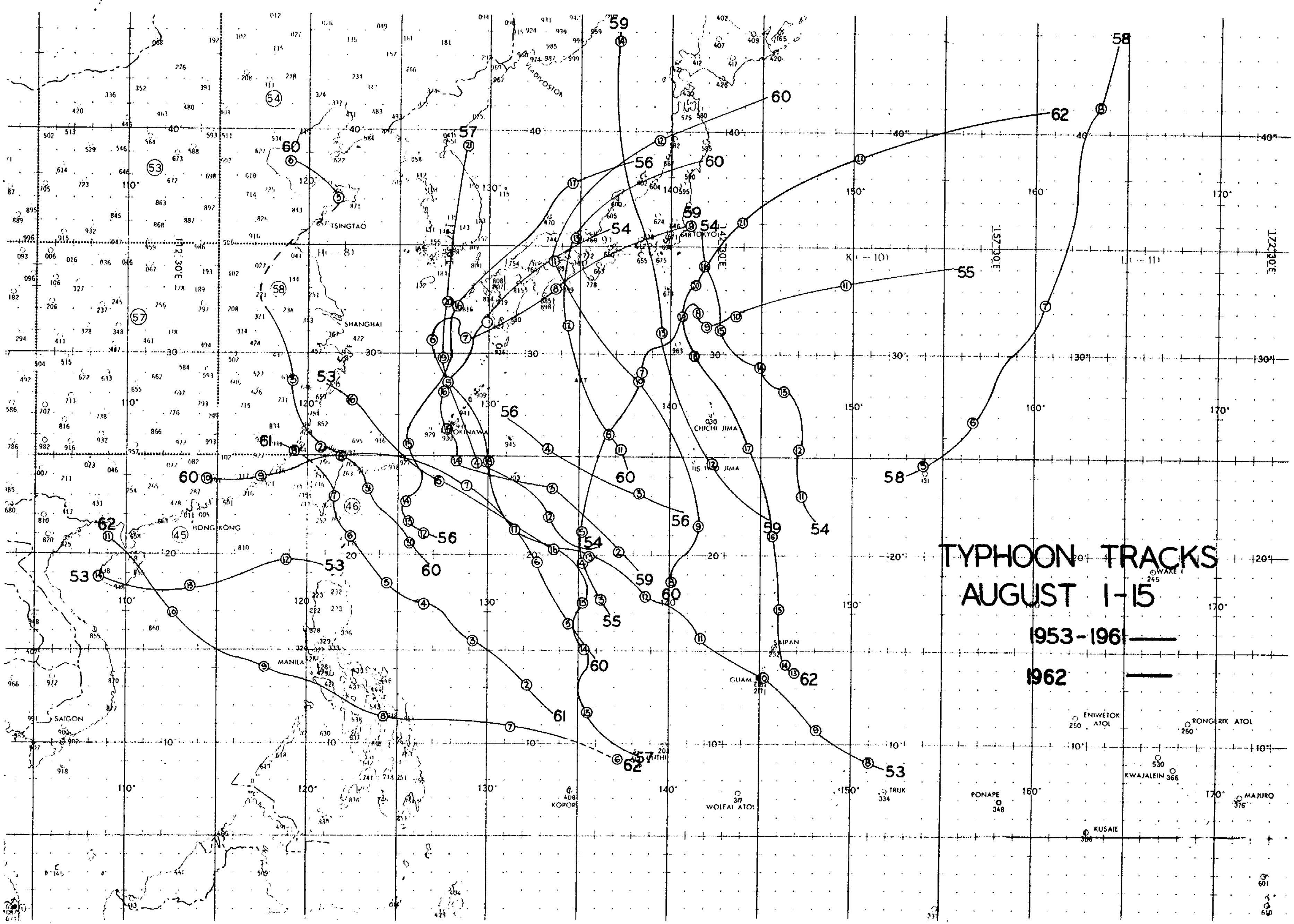

TYPHOON TRACKS
MAY
1953-1961
1962
TSINGTAO
SHANGHAI
OKINAWA
CHICHI JIMA
IWO JIMA
TOKYO
HONG KONG
MANILA
SAIPAN
GUAM
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
WAKE I
KWAJALEIN
MAJURO
NAURU I

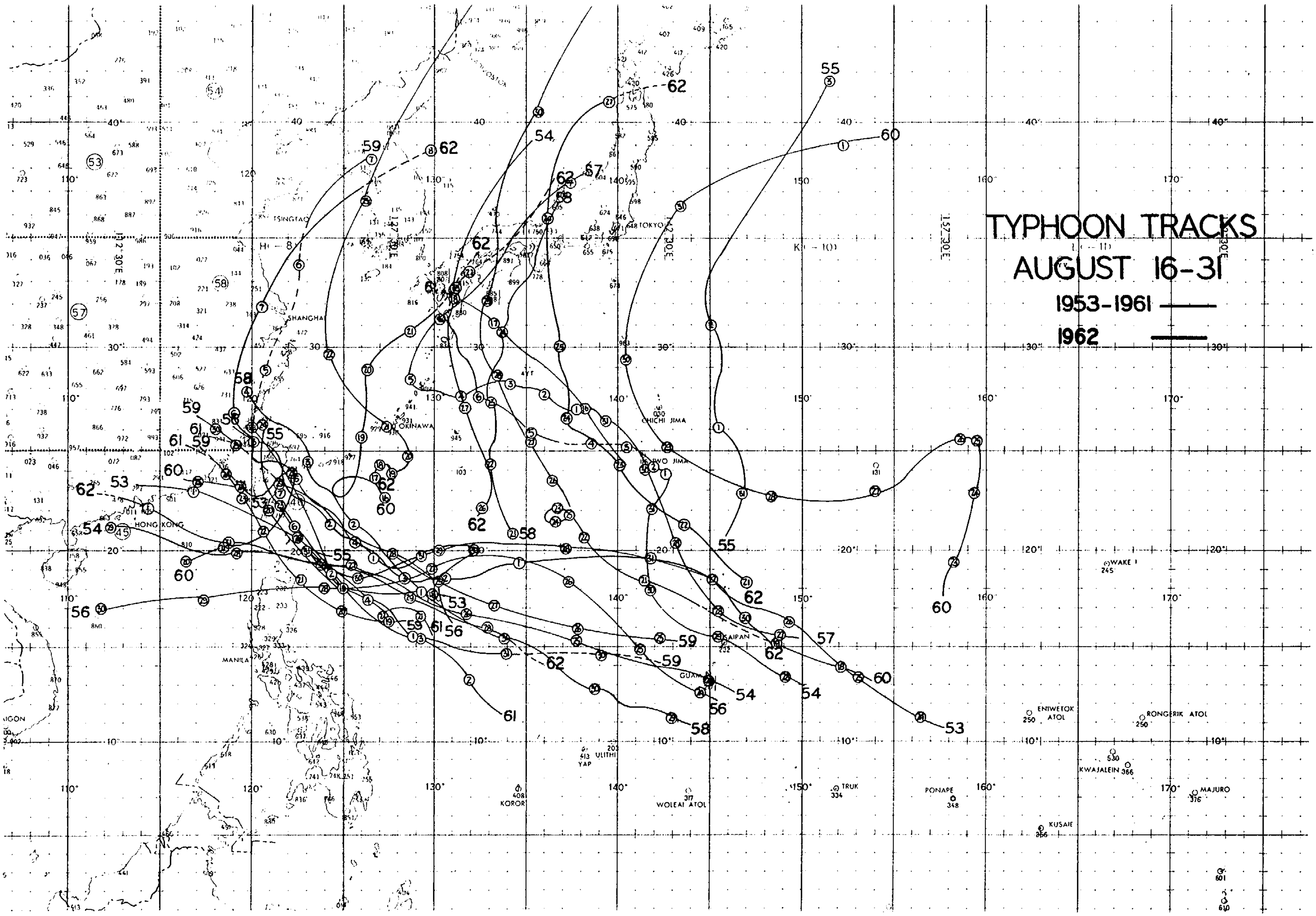


TYPHOON TRACKS
JUNE
1953-1961
1962-NONE
TSINGTAO
SHANGHAI
TOKYO
HONG KONG
MANILA
SAIGON
OKINAWA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I
NAURU I

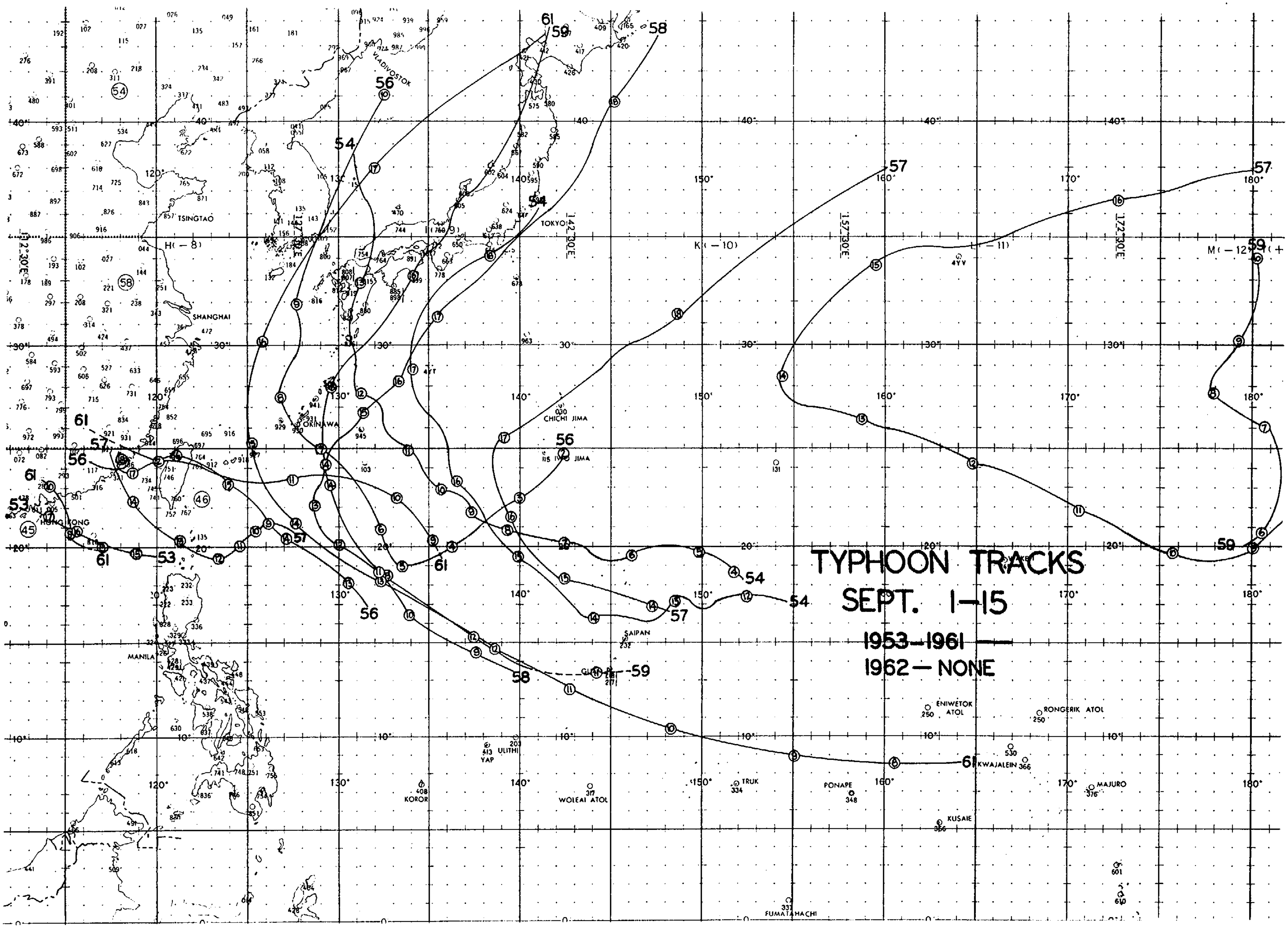

TYPHOON TRACKS
JULY 1-15
1953-1961
1962
VLADIVOSTOK
TSINGTAO
SHANGHAI
TOKYO
OKINAWA
CHICHI JIMA
IWO JIMA
HONG KONG
SAIGON
SAIPAN
GUAM
WAKE I
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
PONAPE
TRUK
KOROR
WOLEAI ATOL
KUSAIE
MAJURO

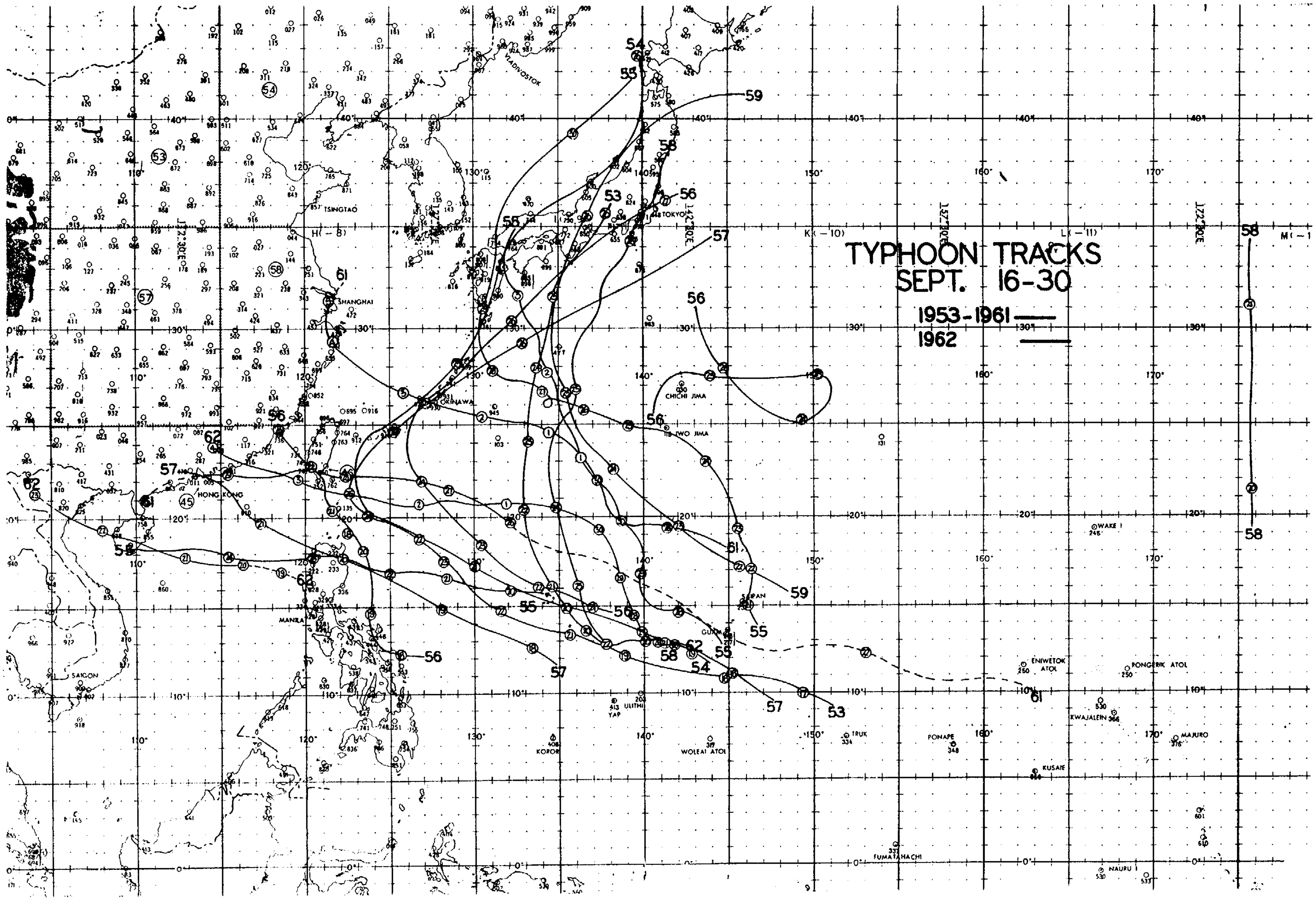

TYPHOON TRACKS
JULY 16-31
1953-1961
1962
VLADIVOSTOK
TSINGTAO
SHANGHAI
HONG KONG
MANILA
SAIGON
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
KWAJALEIN
RONGERIK ATOL
MAJURO
WAKE I
NAURU
FUMATAHACHI

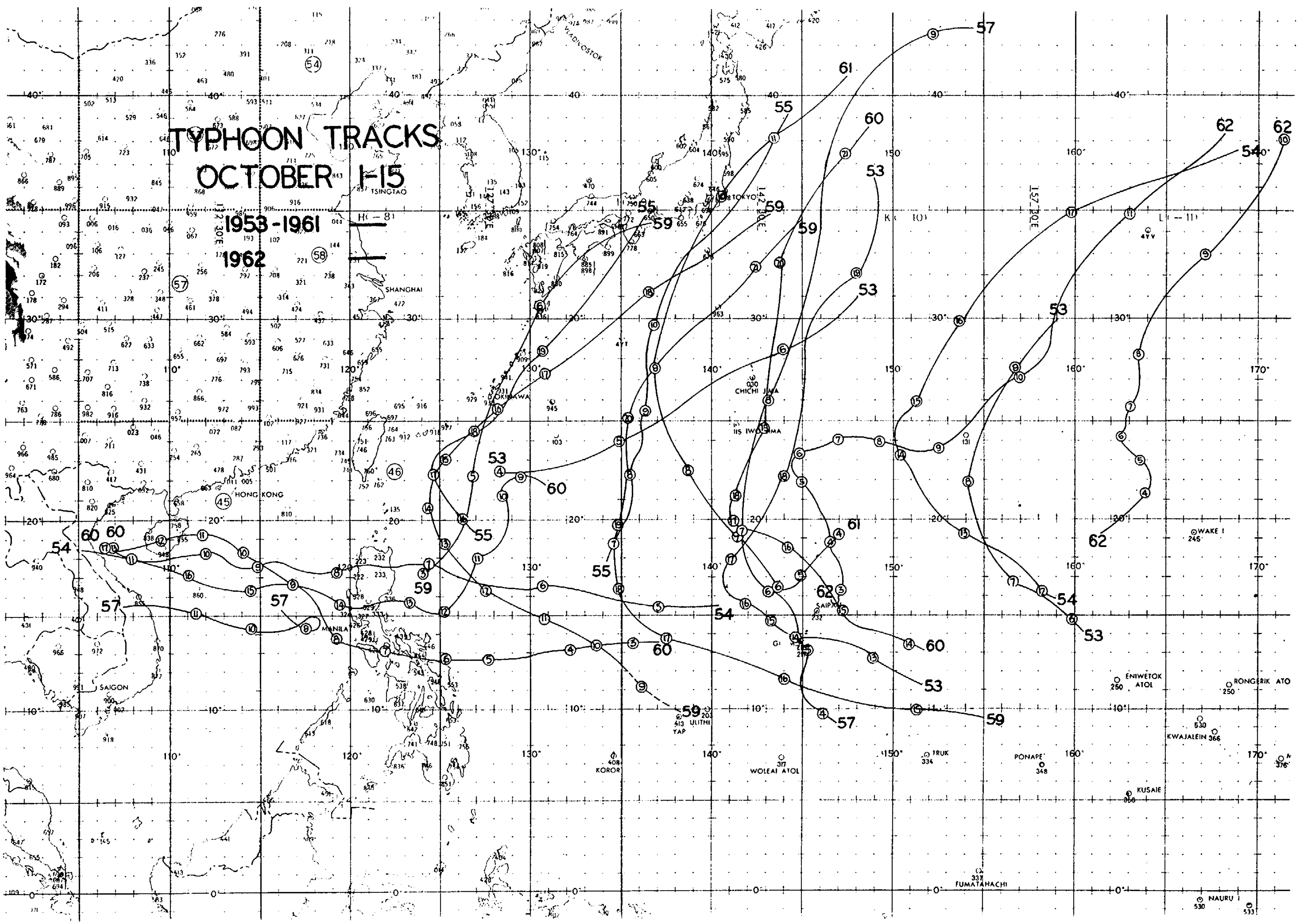

TYPHOON TRACKS
AUGUST 1-15
1953-1961
1962
VLADIVOSTOK
TSINGTAO
SHANGHAI
OKINAWA
TOKYO
CHICHI JIMA
HONG KONG
MANILA
SAIGON
GUAM
SAIPAN
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I

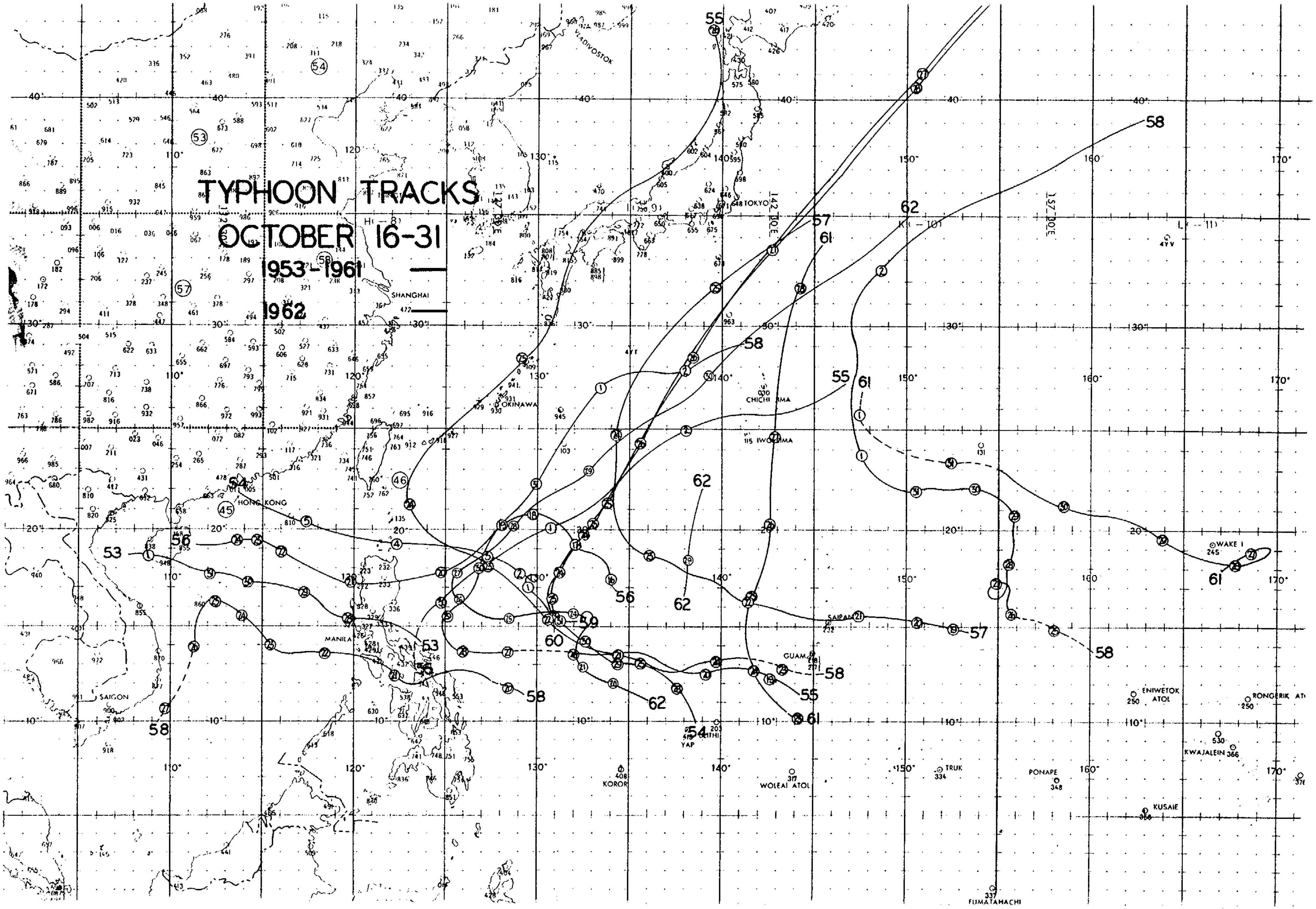

TYPHOON TRACKS
AUGUST 16-31
1953-1961
1962
HONG KONG
SHANGHAI
TSINGTAO
OKINAWA
MANILA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
KWAJALEIN
MAJURO
ENIWETOK ATOL
RONGERIK ATOL
WAKE I

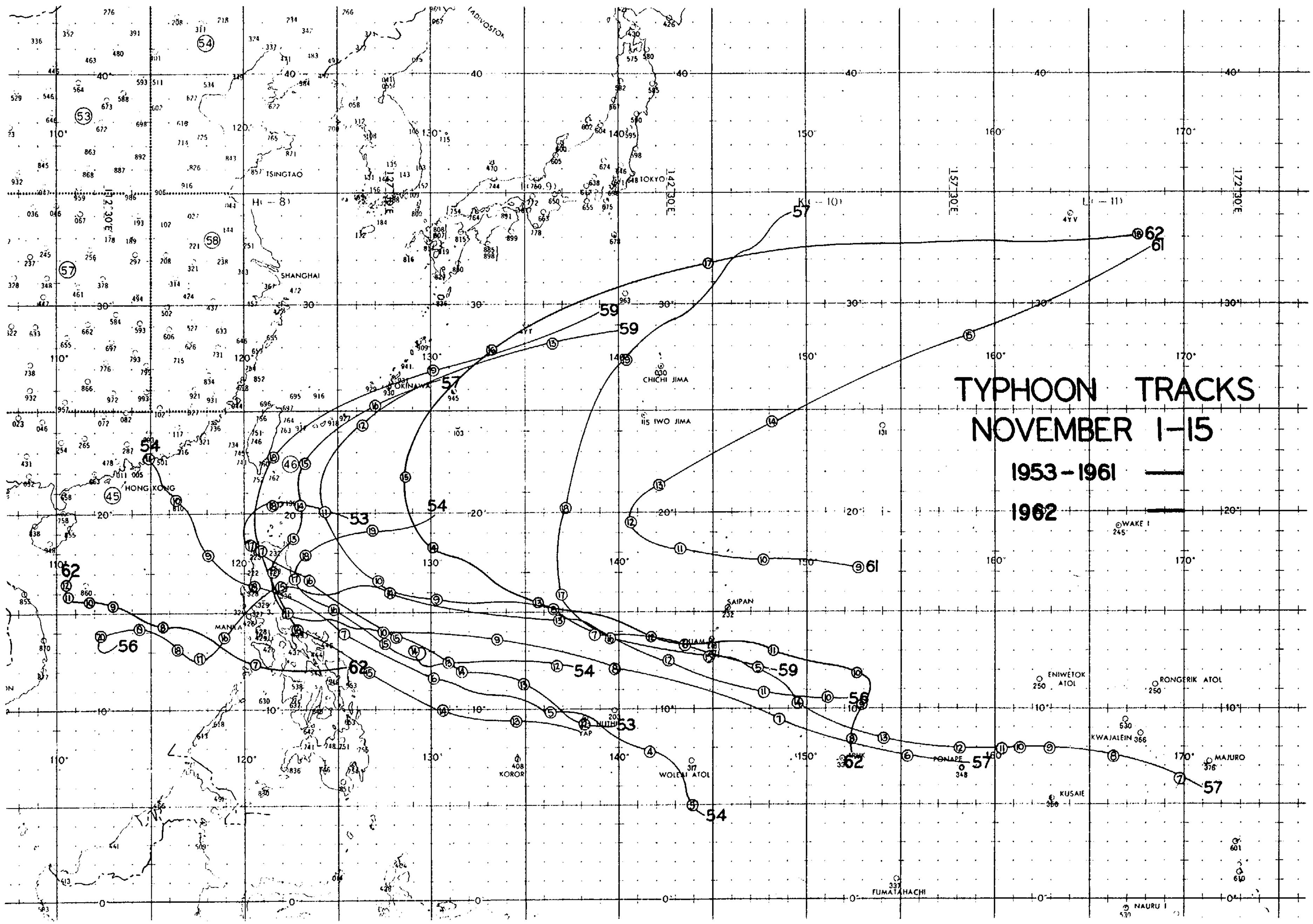
287

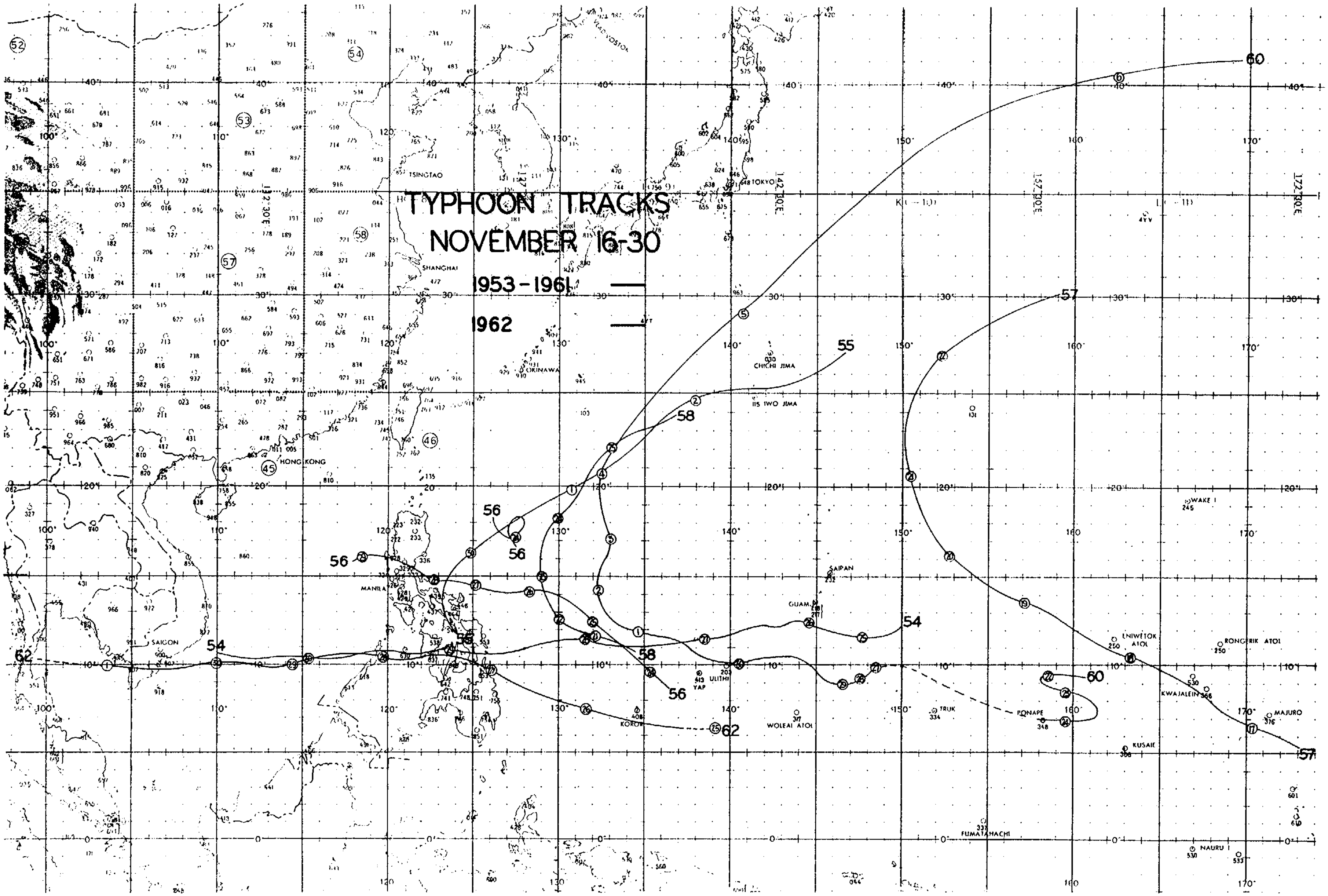

TYPHOON TRACKS
SEPT. 1—15
1953—1961 —
1962—NONE
VLADIVOSTOK
TSINGTAO
SHANGHAI
OKINAWA
TOKYO
CHICHI JIMA
HONG KONG
MANILA
SAIPAN
YAP
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO

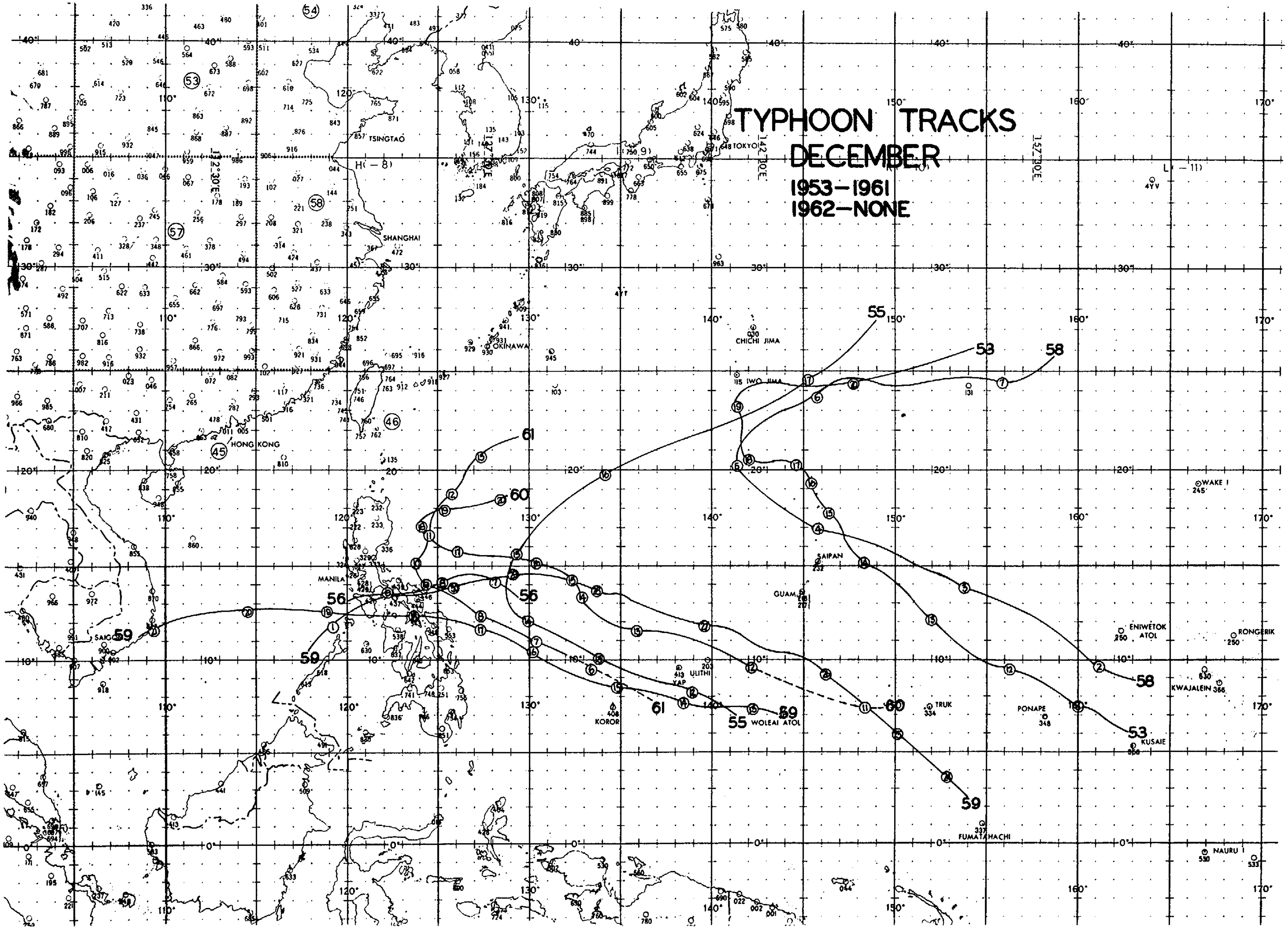

TYPHOON TRACKS
SEPT. 16-30
1953-1961
1962
SHANGHAI
TSINGTAO
VLADIVOSTOK
TOKYO
OKINAWA
CHICHI JIMA
IWO JIMA
HONG KONG
MANILA
SAIGON
SAIPAN
GUAM
WAKE I
ENIWETOK ATOL
PONGERIK ATOL
KWAJALEIN
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
MAJURO
NAURU I
FUMATAHACHI


TYPHOON TRACKS
OCTOBER 1-15
1953-1961
1962
HONG KONG
SHANGHAI
TSINGTAO
MANILA
SAIGON
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
KWAJALEIN
ENIWETOK ATOL
RONGERIK ATOL
WAKE I
NAURU I
FUMATAHACHI
VLADIVOSTOK


TYPHOON TRACKS
OCTOBER 16-31
1953-1961
1962
VLADIVOSTOK
SHANGHAI
TOKYO
OKINAWA
HONG KONG
MANILA
SAIGON
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
ENIWETOK ATOL
KWAJALEIN
KUSAIE
WAKE I


TYPHOON TRACKS
NOVEMBER 1-15
1953-1961
1962
TSINGTAO
SHANGHAI
HONG KONG
MANILA
OKINAWA
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
WAKE I
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
NAURU I


TYPHOON TRACKS
NOVEMBER 16-30
1953-1961
1962
TSINGTAO
SHANGHAI
OKINAWA
HONG KONG
MANILA
SAIGON
TOKYO
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
YAP
ULITHI
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I
NAURU I


TYPHOON TRACKS
DECEMBER
1953-1961
1962-NONE
TSINGTAO
SHANGHAI
TOKYO
HONG KONG
OKINAWA
CHICHI JIMA
IWO JIMA
MANILA
SAIGON
SAIPAN
GUAM
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
KWAJALEIN
ENIWETOK ATOL
RONGERIK
WAKE I
NAURU I
FUMATAHACHI